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Impact of Coal Refuse Disposal on Groundwater

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Mining, Wroclaw (Poland)

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IMPACT OF COAL REFUSE DISPOSAL ON GROUNDWATER

by

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16. ABSTRACT

The objective of this study was to determine the extent of groundwater quality deterioration when coal mine refuse and power plant ashes were disposed of in open pits. In addition, disposal methods were developed and procedures for planning and designing disposal sites were formulated. The study was conducted from 1975 to 1979 at an abandoned sand pit near Boguszowice, Poland, where the groundwater was monitored. Laboratory testing of the wastes and its leachates were also conducted. From this work, the physical-chemical character of the waste material and its susceptibility to leaching of particular ions in the water environment were determined, as was the influence of precipitation on the migration of pollutants to the aquifer. The level of pollution of groundwater in the vicinity of disposal sites and its dependence on local hydrogeological conditions, and particularly on hydraulic gradients were ascertained. Recommendations for improved waste storage technology in order to limit the effect on groundwater and design guidelines for a monitoring system are presented.

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FOREWORD

Over the past nine years a continuing cooperative venture has developed between the United States Environmental Protection Agency (EPA) and the Central Research and Design Institute for Openpit Mining (POLTEGOR) in Wrocław, Poland, to deal with energy and the environment. This research is fundamental to the growing energy requirements and related environmental concerns of the Polish Peoples Republic and the United States. Each country shares similar features enabling the research efforts to be applicable and timely.

Several projects have been undertaken, including those relating to mine water purification, reclamation of spoils, and coal ashes. These research efforts are the necessary first steps in problem solution, which involves defining the problem, measuring its impact, and searching for solutions. The EPA develops new and improved systems technology to minimize the adverse economic, social, health and aesthetic effects of pollution. This publication is a product of that research.

This report presents the results of five years investigation of the effects of coal wastes and ashes on groundwater modelling to identify potential impacts. Further, a most significant aspect of the report is the design testing to determine appropriate monitoring and containment measures to prevent and analyze potential pollution problems. This report and its findings will significantly benefit EPA in its mission. In particular, certain current pollution problems as defined by the Federal Water Pollution Control Act, Resource Conservation and Recovery Act and Safe Drinking Water Act, can be dealt with more effectively as a result of this report. Further, the findings should have benefit not only to disposal of coal refuse, but disposal of toxic wastes in general.

ABSTRACT

This project was developed as a result of an earlier study published in the EPA report "Effects of the Disposal of Coal Wastes and Ashes in Open Pits" (EPA 600/7-78-067). The analysis of that study indicated the need to continue the research on a full scale basis for a longer period of time, thus the initiation of this study.

The objective of this study was to determine the extent of groundwater quality deterioration when coal mine refuse and power plant ashes were disposed of in open pits. In addition, disposal methods were developed and procedures for planning and designing disposal sites were formulated. The study was conducted from 1975 to 1979 at an abandoned sand pit near Boguszowice, Poland, where the groundwater was monitored. Laboratory testing of the wastes and its leachates were also conducted. From this work, the physical-chemical character of the waste material and its susceptibility to leaching of particular ions in a water environment were determined, as was the influence of precipitation on the migration of pollutants to the aquifer. The level of pollution of groundwater in the vicinity of disposal sites and its dependence on local hydrogeological conditions, and particularly on hydraulic gradients were ascertained. Recommendations for improved waste storage technology in order to limit the effect on groundwater and design guidelines for a monitoring system are presented.

This report was submitted in fulfillment of project JB-5-537-1 between the United States Environmental Protection Agency and the Central Research and Design Institute for Openpit Mining (POLTEGOR), 51-616 Wroclaw, Rosenbergów 25, Poland.

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The entire research was directed, and the report prepared by the Principal Investigator, Dr. Jacek Libicki, with assistance from Mrs. Helena Hac, M.Sc. geologist, and Mrs. Marianna Szatan, M.Sc. mathematician who developed the statistical analyses.

The Project Officer was Mr. Stephen Wassersug from the EPA Regional Office in Philadelphia. The Project Officer advised us during the project and provided contacts of appropriate institutions in the U.S.A. This enabled us to fully understand American needs and adjust the project and final report to U.S. environmental requirements.

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SECTION 1

INTRODUCTION

The current situation in world energy which began in the 1970's, prompted renewed interest in coal. It is expected that this situation will last until the end of the 20th century. Increases in coal extraction result in large amounts of refuse being produced mainly from processing plants. These wastes are partially utilized (e.g., for road embankments), but large amounts have to be disposed frequently in previously exploited open-pit mines. This seemingly rational solution is, however, potentially hazardous to groundwater which can be easily contaminated by the direct or indirect contact with the refuse. A conflict thus develops because these groundwater resources are frequently used by municipalities and industries and have to be protected. Many countries regulate groundwater pollution.

Influence of coal waste and ash disposal on groundwater quality was investigated between 1973-1976 in the Central Research and Design Institute for Open-pit Mining (POLTEGOR) as a part of the Environmental Protection Agency's overseas activities. A small test disposal site with a capacity of 1,600 m^3 was used to investigate the influence of ash and refuse disposal on groundwater quality. Similar tests were also conducted for a period of time on a large disposal site with a capacity of 2,000,000 m^3, where its impact on groundwater quality was observed within a radius of 1 km. Tests were also performed on ground models and analog models in order to investigate pollutant migration in groundwater.

Upon completion of the project, U.S. EPA published the Final Report in the Interagency Energy-Environmental Research and Development Series (Publication EPA-600/7-78-067). This report presented a number of conclusions relating to the pollution hazard and a number of recommendations relating to methods to reduce the hazard.

In 1976, it was decided to verify the conclusions by further studies at the large disposal site. Investigation for longer than two years, especially in the case of large disposal sites and groundwater migration, was found to be necessary. Thus, the period of evaluation was extended to five years.

This report presents the results of the five-year study (1975-1979) on the large refuse disposal site and its impact on groundwater quality. Conclusions have been drawn and recommendations made.

SECTION 2

CONCLUSIONS

1. This research confirms that coal refuse disposal in an abandoned open pit in which the refuse may have contact with an underlaying aquifer, deteriorates groundwater quality (Table 2-1).

2. The stored coal refuse consists of dry wastes coming from the construction of the mine, from dry separation of coal waste and wet refuse coming from coal washers. Dry waste materials as a rule consist of large particles, having diameters greater than 100 mm, and as such constitute a much smaller pollution potential because the leaching of toxic components is limited by small facial surfaces in contact with water. Washed waste material has smaller particles ranging from a dusty fraction to 50 mm, and is much more susceptible to leaching of soluble components.

3. Dry refuse, because of its large size particles, presents difficulties in laboratory tests (in columns) and it is therefore difficult to relate laboratory leaching results with field observation. Washed refuse also presents difficulties for laboratory testing because the suspended solids and colloidal particles plug the bed.

4. The level of groundwater contamination is dependent first of all on the leachability of the wastes. Other significant factors include:

   - the amount of precipitation percolating into the disposal site which is dependent on the area of disposal surface exposed to precipitation and amount of precipitation,

   - selfsealing of the disposal site bottom by the finest muds washed out from the disposal site, and settled at the aquifer roof (especially if the permeability of the aquifer is less than the permeability of the disposal site).

5. The leaching of refuse in glass columns in the laboratory in order to obtain the pollution impact was accomplished in three phases of 24 hours each. These tests showed the maximum concentration of each component in the laboratory leachate and the dependence of leachability on time.
   After 72 hours (three 24-hour periods), the following concentration of each component was found in the leachate (maximum values): TDS - 3372 mg/dm^3*; Cl - 479 mg/dm^3, SO_4 - 230 mg/dm^3, Na - 357 mg/dm^3, K - 48.0 mg/dm^3, Ca - 355.9 mg/dm^3, Mg - 21.85 mg/dm^3,

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* - 1 mg/dm^3 = 1 mg/l = 1 ppm

Table 2-1. Comparison of Groundwater Quality Before and After Waste Storage

Designation	Unit	Average concentration before disposal influence	Average concentration during disposal influence	Maximum concentration during disposal influence
pH		6.66	6.25	6.88
Conductivity	µs/cm^2	247.1	460.72	801.0
TDS	mg/dm^3	169.2	329.13	550.07
Cl	"	15.08	40.84	72.73
SO_4	"	54.1	117.98	209.89
Na	"	7.84	33.50	81.99
K	"	2.77	5.51	11.31
Ca	"	16.26	34.11	53.60
Mg	"	4.95	10.23	17.39
Mn	"	0.24	0.266	0.79
Fe total	"	4.60	3.7433	8.75
NH_4	"	0.43	1.22	2.47
PO_4	"	0.014	0.0244	0.053
CN	"	0.0049	0.0059	0.0172
Phenols	"	0.0034	0.0036	0.0066
Al	"	0.16	0.181	0.444
Zn	"	0.360	0.1672	0.497
Cu	"	0.023	0.0102	0.0313
Pb	"	0.0165	0.0246	0.047
Cr	"	0.0064	0.0056	0.075
As	"	0.0168	0.0274	0.057
Sr	"	0.130	0.1472	0.216
Mg	"	0.630	0.6294	1.300
Cd	"	0.0024	0.0037	0.0058
Mo	"	0.0148	0.0083	0.024
B	"	0.032	0.0685	0.095

Note: mg/dm^3 = mg/l = ppm

Mn - 2.995 mg/dm^3, Fe total - 75.8 mg/dm^3, NH_4 - 4.46 mg/dm^3, PO_4 - 3.14 mg/dm^3, CN - 0.066 mg/dm^3, Phenols - 0.088 mg/dm^3, Al - 38.5 mg/dm^3, Zn - 3.085 mg/dm^3, Cu - 0.925 mg/dm^3, Pb - 0.271 mg/dm^3, Cr - 0.089 mg/dm^3, As - 0.133 mg/dm^3, Sr - 2.050 mg/dm^3, Hg - 1.09 mg/dm^3, Cd - 0.056 mg/dm^3, Mo - 0.029 mg/dm^3, B - 3.6 mg/dm^3.

6. The leachability of pollutants may be divided into three groups under laboratory conditions:
   1st group - the components most easily leached (Cl, SO_4, Na, K)
   2nd group - the components of medium leachability (Cu, Zn, Hg, Sr, Cd, B, Mn, Mo, CN)
   3rd group - the components characterized with the slowest leaching (Mg, Al, Cr, As, Pb, NH_4, Ca).

7. The glass columns leaching experiments showed that from 1 kg of coal wastes the following masses of particular pollutants were leached on the average:
   TDS - 320 mg/kg, Cl - 41.8 mg/kg, SO_4 - 32.9 mg/kg, Na - 48.74 mg/kg, K - 5.26 mg/kg, Ca - 15.18 mg/kg, Mg - 1.46 mg/kg, Mn - 0.146 mg/kg, Fe - 4.93 mg/kg, NH_4 - 0.347 mg/kg, PO_4 - 0.104 mg/kg, CN - 0.005 mg/kg, Phenols - 0.0056 mg/kg, Al - 2.34 mg/kg, Zn - 0.177 mg/kg, Cu - 0.0395 mg/kg, Pb - 0.0391 mg/kg, Cr - 0.0073 mg/kg, As - 0.0016 mg/kg, Sr - 0.081 mg/kg, Hg - 1.03 mg/kg, Cd - 0.005 mg/kg, Mo - 0.003 mg/kg and B - 0.171 mg/kg. These figures could be used to forecast the amounts of leachable pollutants contained in the stored coal wastes.

8. The comparative study showed the relation between the laboratory leachates and the real pollutants' concentrations in the adjacent part of the aquifer, which is shown in Table 2-2. The indicators specified in that table may be used for the rough prediction of the area of pollution when storage is planned based on the laboratory leaching tests.

9. The system of monitoring wells in the shape of 5 radial lines was sufficient to monitor the aquifer for potential pollution. However, in practice a smaller number of wells would be sufficient.

10. Three-week intervals for groundwater sampling and measurements were sufficient, and in practice measurements could be reduced to a monthly frequency.

11. The schedule of physico-chemical analyses (i.e., the sample analyses of 19 parameters for every set of samples, and full analyses of 42 parameters for every third set of samples) is appropriate. However, the number of parameters chosen for simple analyses and full analyses should not be based on recommendations for drinking water standards, but on the basis of results from previous laboratory leaching tests.

12. The first indications of groundwater pollution occurred in the form of singular waves of pollution in specific wells in 1976, i.e., 12 to

Table 2-2. Indicators Illustrating the Comparison of Actual Groundwater Pollution Versus Glass Columns Leachate

Designation	Unit	Maximum	Average	Minimum
pH		0.82	0.75	0.70
Conductivity	us/cm^2	0.53	0.307	0.20
TDS	mg/dm^3	0.34	0.20	0.12
Cl	"	0.35	0.19	0.09
SO_4	"	1.28	0.72	0.36
Na	"	0.34	0.14	0.04
K	"	0.43	0.21	0.10
Ca	"	0.71	0.45	0.23
Mg	"	2.38	1.40	0.74
Mn	"	1.08	0.36	0.15
Fe total	"	0.355	0.152	0.013
NH_4	"	1.43	0.705	0.32
PO_4	"	0.10	0.047	0.017
CN	"	0.68	0.23	0.09
Phenols	"	0.23	0.13	0.07
Al	"	0.038	0.02	0.02
Zn	"	0.56	0.19	0.09
Cu	"	0.5	0.16	0.01
Pb	"	0.24	0.13	0.05
Cr	"	0.21	0.15	0.06
As	"	0.98	0.47	0.08
Sr	"	0.53	0.36	0.23
Hg	"	0.25	0.12	0.05
Cd	"	0.24	0.15	0.09
Mo	"	1.41	0.49	0.13
B	"	0.11	0.08	0.06

Note: Indicator in the table = $\frac{\text{groundwater values}}{\text{leachate column values}}$

18 months after disposal operations had begun. However, these developments were difficult to monitor.

13. Continuous pollution began in early 1977, two years after the commencement of storage operations (see Table 2-3).

14. The waste caused significant pollution of the aquifer only in the direction of the greatest declination in the groundwater table.

15. The pollutants do not migrate in the form of a wide uniform front, as predicted by hydrodynamic net analysis, but migrate in the form of narrow veins. This finding has been proved by comparing the concentration of pollutants in particular wells in the potentially polluted zone. The pollution was not very uniform. The most important finding is that local differences in aquifer permeability determine pollutant concentration (higher permeability - higher pollution) especially after 3 years. This condition was found in similar investigations conducted in France, but without explanation.

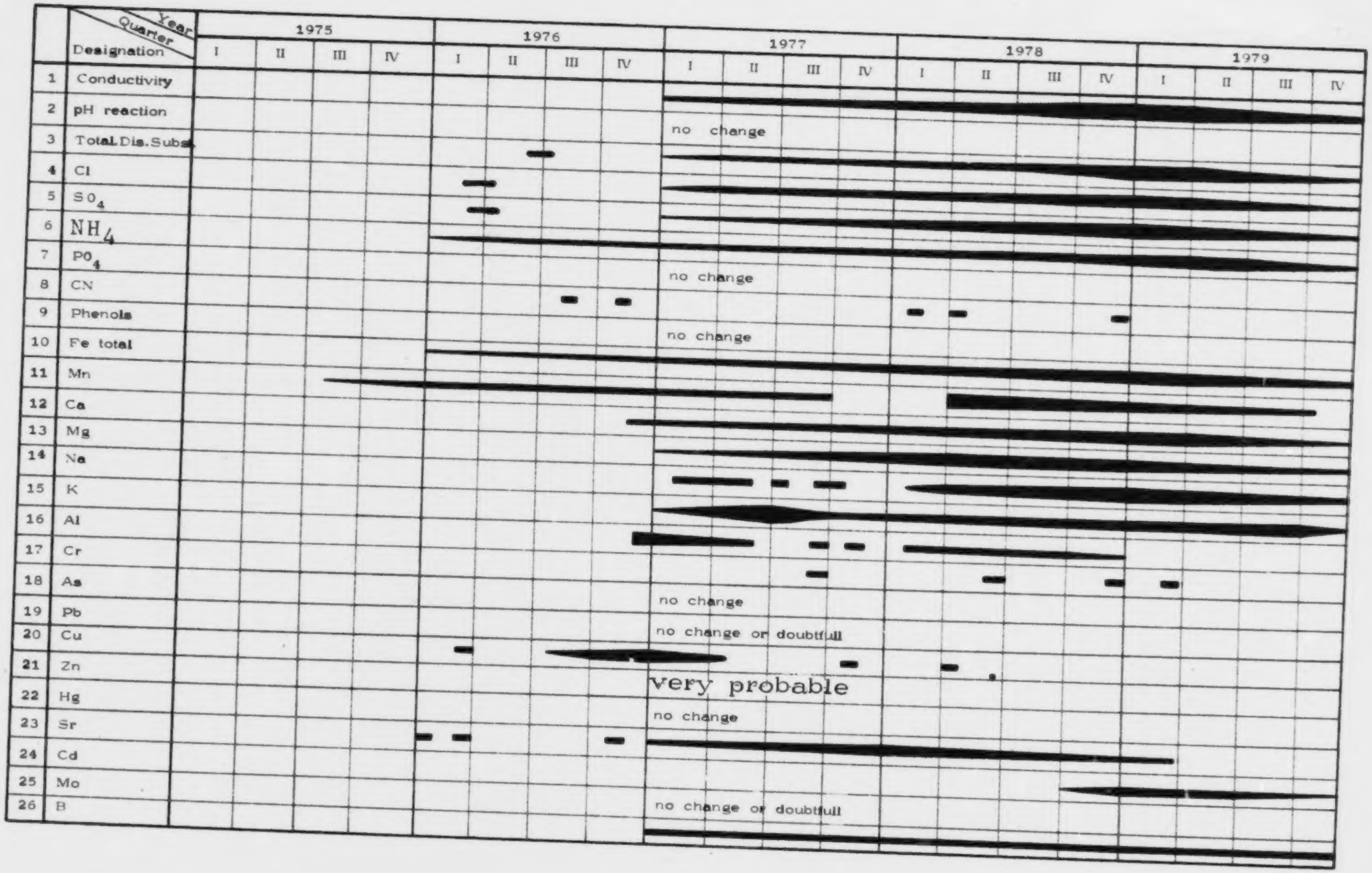
16. The duration of heavy pollution was 2 1/2 years or until mid 1979, when it decreased. This phenomenon could be explained by two factors:

    - the surface area of the disposal site exposed to rain infiltration was reduced by careful reclamation of about 30-40 % of the total disposal surface,

    - the bottom of the disposal site was self-sealed when the silty wastes were washed from the disposal body and settled at the bottom of the pit.

17. In accordance with modelling in the previous report (see section 4), the sequence and period for pollutants occurring in particular wells from the beginning of storage, was predictable with 80 percent accuracy.

Table 2-3. Qualitative Picture Illustrating Pollution Occurrence Intervals



SECTION 3

RECOMMENDATIONS

This project was a follow up to a previous project entitled "Effects of the Disposal of Coal Waste and Ashes in Open Pits", and published by EPA in Research and Development Series in April 1978 under the number 600/7-78-067.

The objective of the present project was on the basis of a long-lasting full scale investigation to confirm the conclusions and recommendations from the previous report. Significant new data on the expanded site was utilized.

This confirmation was required to verify the earlier conclusions and recommendations and to insure its applicability to broad use.

The recommendations have been verified and confirmed in practice. Therefore, the recommendations have been systematically presented to relate its applicability to the first project. The methodology presented for the storage of coal refuse may be applied to many other solid wastes. The phenomena observed may differ according to chemical composition but should be similar hydraulically.

WASTE CLASSIFICATION AND EXAMINATION

1. According to observed tests, coal waste can be divided into the following sub-groups:

   a. Dry waste material is from quarry operations, associated with the ripping of the floor or roof, the construction of stone drifts, etc., and more rarely from dry mechanical separation. This refuse is characterized with identical mineral and chemical composition, from the sterile rocks accompanying the coal seams, and are usually coarsely grained (gross from 10 to 200 mm). The character of pollutants leached is entirely dependent upon the chemical composition of sterile rock formations. The quantity of pollutants which may pass into solution is relatively small, because of the small surface contact with the leaching water. This is due to the effect of the rather large size of particles of this refuse, and great filtration velocity of water through the material which occurs particularly in the disposal located above the ground water table.

   b. Wet waste material may be coming from washers using water or heavy fluids and from flotation processes.

- The refuse from the water washers is characterized with a granulation from a silty fraction up to a diameter of 80 mm, and their chemical composition is effected by both the sterile rock and the cleaned coal. Moreover the influence on their chemical character has the composition of washing water (i.e. a highly mineralized drainage water). The wide range of grain size provides conditions for both the movement of the water through the stored material, and for large quantities of components to be leached as compared with dry refuse. Moreover some pollutants may also be washed in the form of suspension of silty fractions.

- Waste material coming from washers using heavy fluids are characterized by a coarser graining than waste from water washers (i.e. grain size of 20 to 250 mm). Their chemical composition is effected by the character of the sterile rocks and cleaned coal. The chemical composition of the heavy fluids used has a substantial influence during washing. Here the components of the washing medium settle on the surfaces of refuse particles, and are first washed-out from the disposal. Therefore, the chemical character of this fluid should be considered from the environmental perspective. The coarser granulation of this refuse, in comparison with the preceding, does not provide conditions for the leaching of as large a quantity of pollutants as for water washes because (a) of the relatively smaller contact surface of the refuse particles with the percolating water, and (b) due to the higher velocity of the rain water percolation through coarser material.

- The refuse from flotation is characterized with a very fine granulation in fractions from silty to 2 mm diameter. Their chemical composition is a function of the coal characteristics, characteristics of accompanying sterile formations, and also the chemical substances used as flotation fluids. The fine granulation of these wastes provides conditions for leaching large quantities of components particularly in disposals saturated with water. In case of dry disposals (e.g. above groundwater table), a fine granulation of this refuse limits the possibility of the filtration of the rain water through the stored material and may increase the share of evaporation in the disposal's water balance. The composition of the fluid used in the flotation process may also have substantial influence on the chemical character of leachates because some of the fluid's components may settle on the surface of grains. The type of fluids used in flotation should therefore also be controlled for potential ground water pollution.

2. Laboratory tests of wastes, with respect to their storage, should be carried out considering the conditions of storage.

3. With reference to the above, the full chemical analyses of refuse are not recommended, as this can lead to erroneous conclusions. Only a portion of the refuse components can pass into leachate, and only this portion affects the quality of groundwater.

4. With sufficient time and funds, the lysimetric method of refuse analyzing is recommended when conducted in columns of 1 m diameter, and 3-4 m high. These tests may be conducted under full saturation of refuse, if storage below the groundwater table is expected or where the refuse is only temporarily impacted with rain, if disposal above the groundwater table is expected. In the first case the duration of tests has to be defined on the basis of refuse permeability. A duration of 3 to 6 months is recommended. In the second case a duration of at least one year is recommended. The water for the tests in the first case should be taken from the aquifer within which the disposal is planned. In the second case the recommendation is to expose the refuse to the natural rain. Distilled water to simulate rain is not recommended because the rains in the industrialized areas are generally acidic (pH = 4-6) containing pollutants.

5. To obtain fast and approximate results, an expedited leaching of the refuse can take place in 10 cm diameter columns about 1 m in height with a filtrating layer in the bottom part. In two weeks approximate results on maximum concentrations of particular components passing to groundwater in optimal conditions can be obtained, and also the amount of leachable pollutants per unit of mass of stored wastes. In interpretation of these results caution is recommended where solubility may be impacted by increased time.

6. It is recommended that tests as described in no. 4 be performed for planning before commencing storage, and tests referenced in no. 5 be performed during storage to determine variability of the stored material.

7. In order to plan and design the disposal site, the chemical analyses of leachates should analyze all components and elements to estimate which could be harmful to groundwater quality.

8. The chemical analyses of leachates, obtained in the laboratory process of the stored refuse, may comprise only those elements and compounds which were found harmful during the basic examination mentioned in no. 7. This shortened procedure may be used if the coal and sterile material has approximately uniform characteristics.

9. The analyses of the leachate should determine all related physical-chemical parameters, as one cannot judge beforehand which may be harmful.

10. Analyses mentioned in no.7 should be completed with a high degree of accuracy to determine not only the potential threat from a given toxic component in groundwater, but also the secondary impact from organisms of plants or animals using these waters. This secondary concentration may be more harmful.

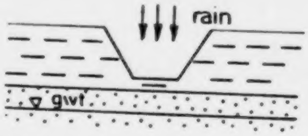
SITE CLASSIFICATION

Classification and evaluation of the open pits for the storage of coal refuse, for groundwater protection, should consider the following criteria:

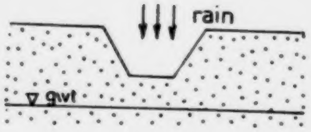
I. The hydrogeological criteria based on reciprocal spatial relations of the disposal and the threatened aquifer is discussed in the following classifications:

A. "Dry" disposal sites (situated above the groundwater table and exposed to rain).

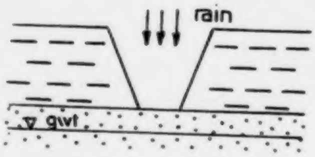
1. localized within the impermeable layer (i.e. clay pit)



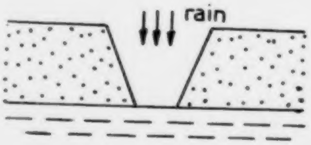
2. localized within the permeable layer (i.e. sand pit)



3. localized within the impermeable layer, underlined with unsaturated permeable layer (i.e. clay pit)

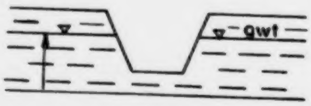


4. localized within the unsaturated permeable layer and underlined with impermeable layer (i.e. sand pit).

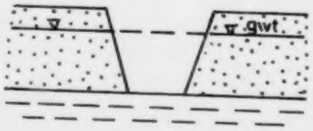


B. "Wet" disposal sites (situated below the ground water table)

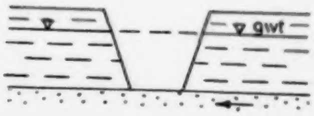
1. localized within the impermeable layer underlined with aquifer with hydrostatic pressure



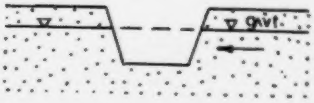
2. localized within the permeable layer underlined with impermeable layer



3. localized within the impermeable layer directly underlined with aquifer with hydrostatic pressure

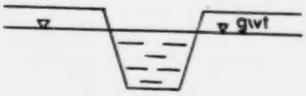


4. localized within the permeable layer.



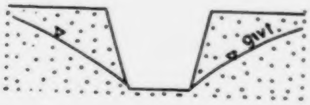
The disposals mentioned in B. 2, 3 and 4 could be:

a) wastes completely saturated



or

b) dry by existing (from the period of excavation) draining arrangements, i.e., ditches, pumping stations - refuse is stored in dry pit and then is saturated with water.



In the first of these two cases, the pollutants pass into water much faster. In the second, there is a much slower rate although the of leached out compounds in an extended period will be more or less equal.

II. Hydrogeological criteria based on the relationship between the disposal and aquifer permeability.

A. disposals with the permeability lower than the surrounding aquifer (mostly disposals of floating refuse)

B. disposals with permeability higher than the aquifer or a majority of disposals

C. disposals with permeability similar to the surrounding aquifer.

III. Criteria for a protected object is recommended to distinguish disposals when:

A. the entire aquifer must be protected

B. a determined part of the aquifer or the particular water intakes must be protected.

IV. Criteria for positioning the disposal and the protected object:

A. protected object is situated in the threatened zone posed by groundwater being in direct contact with the disposal (downstream in the groundwater flow)

B. protected object is situated in the indirect influence zone where pollutants may appear either as very diluted or as a result of dispersion

C. protected object is situated within the same aquifer, but outside the hydrodynamic or dispersional influence of disposal (e.g., upstream in the groundwater flow).

V. Distinguishing criteria for the degree of groundwater protection is recommended:

1st degree - total protection, when the groundwater quality cannot be changed at all,

2nd degree - partial protection, when permissible values cannot be exceeded or water must be protected against increases of determined components (i.e., Cl, SO_4, heavy metals),

3rd degree - when a given aquifer is not subject to special protection.

PLANNING AND DESIGNING FOR DISPOSAL

I. Planning the storage of the coal refuse in an open pit should be preceded by:

- exact knowledge of the coal refuse characteristics including their leachability based on tests described above and the quantity planned for storage over a given time. For preliminary studies the figures and indicators contained in section 2 of this report may be used,
- detailed investigation of the hydrogeological conditions of the area planned for storage, and
- determining the spatial and qualitative protection of the aquifer.

II. The survey of hydrogeological conditions should include:

- spatial parameters of the aquifer in contact with the disposal (thickness, spreading and hydraulic relations with others),
- parameters of permeability (especially coefficients of permeability and of specific yield),

- distribution of a hydrodynamic network of the groundwater hydrostatic heads,
- exact knowledge of the original groundwaters' chemical characteristics,
- lithology of aquifer,
- detailed description of the site slopes and bottom considering permeability,
- detailed knowledge of climatological conditions, especially the amounts and distribution of rainfall.

III. Hydrogeological parameters that should be used with the survey of the aquifer are:

- drilling wells (either existing from the period of the deposit exploitation, or specially designed),
- geophysical investigations (where possible),
- analysis of general geological information.

IV. Parameters of permeability should be determined using standard field tests (e.g., pumping tests, or water forcing in the zone of aeration) or laboratory tests (in filtration columns, and sieve analyses).

V. Reconstruction of the hydrodynamic network should be performed on the basis of surveys of the groundwater table in bore holes, or where possible with use of remote sensing geophysical methods. The thermistor or tracer methods are not recommended for large sites and non-point pollution, since they are less adequate than in the case of particular wells. The mathematical model verification of the hydrodynamic network is recommended since there are better possibilities to adjust to real conditions. Knowledge of the region's hydrodynamic network is one of the most important elements in determining the disposal's eventual influence on groundwater and should be made with the greatest accuracy. The proper reconstruction of the hydrodynamic network and good knowledge of permeability will allow the possibility of highly accurate forecasts.

VI. The use of aerial photography is strongly recommended to define the lineaments to delineate potential groundwater carrying pollutants. The pollutants are not transported through the whole section of the aquifer, but through the flumes which could be located only with use of remote sensing methods.

VII. The chemical characteristics of water of a considered aquifer should be determined by analyses of groundwater. Sampling should be done from the points specified based on the previously described investigations at 2-3 month intervals (at least one year prior to storage).

This is necessary to determine seasonal or other factors such as influence from an urbanized area.

VIII. Knowledge of lithology of the aquifer formations is necessary for the evaluation of absorption and ion exchange that can take place between the polluted water and the rock (soil) skeleton.

IX. The requirements of aquifer protection should take into account current and future plans for water use since disposal impacts may exist for several years.

X. After collecting appropriate data, it is possible to forecast the influence of coal refuse storage in an open pit on a selected part of the aquifer, or on the entire aquifer under consideration. Such a forecast may be of qualitative or quantitative character, both in respect to time and the degree of deterioration of the groundwater quality. The forecast may be prepared either using computer methods, or a descriptive computation method. One should realize that there are no all purpose programs which would afford a formulation of all phenomena, in a three dimensional system from the aspect of time and considering different behaviour of various ions. The problem is more difficult as the phenomena occurs in the unsaturated zone. One can make approximate forecasts enabling improved decision making. It is possible to obtain more accurate results when the forecast concerns one pollutant only, e.g., chlorides, or molybdenum, as opposed to polluting components.

XI. The forecast and its conclusions should be followed by recommendations concerning the method of storage and eventual prevention means as needed.

XII. For particular types of disposal sites the following is recommended:

A. In open pits of the I-a type, the coal refuse can be stored without any limitations.

B. In open pits of the I-b type, coal refuse cannot be stored without a risk of groundwater pollution. This threat can be reduced by 70 to 90 percent by the protection of the disposal surface against leaching of precipitation. This can be achieved by altering surface contours to maximally increase the superficial run-off of rain water and the evaporation, and to decrease to a minimum the leaching of precipitational water to the disposed refuse. Covering the surface with impermeable material is also recommended (e.g., clay layer), making infiltration of precipitation impossible into the disposal interior and to reclaim (revegetate) the surface as soon as possible. When mixed wastes are stored, it is recommended that coarse wastes be placed on the bottom and a fine material on the top of the disposal to reduce further the infiltration rate.

There are limits to the above methods, including whether several waste levels must be filled successively and immediate reclamation is impossible. In some cases, a temporary sealing of the surface with a plastic sheeting, or total sealing of the bowl of the open pit is recommended.

Relevant decisions should also depend on the required degree of groundwater protection and on spatial relations of the disposal to the protected object.

C. For the openpits of type I-c and I-d, the hazard is similar but smaller. Therefore, the recommendations are similar, but less restrictive.

D. In the openpit of the II-a type, one may store coal refuse without any greater limitations.

E. In openpits of the II-b type, the storage of any kind of wastes will cause a deterioration in quality of the groundwater. This pollution is directly dependent on the amount of water flowing through the disposal, and so will be affected by the relationship of permeability of the disposal and of the surrounding aquifer. In this type of disposal, the pollutants will flow through the entire aquifer. Further, the waste can be stored only when the degree of required protection will be of the 2nd or 3rd rank, and when the forecast shows that the permitted pollution in a given point is not expected to be exceeded. When the 1st degree of water protection is required, or when the permitted pollution level is exceeded, preventative means are necessary, including:

- vertical sealing diaphragm, down to the impermeable layer, made by digging and filling with impervious material or by grouting method,
- protection of slopes with impermeable plastic sheeting, or sprinkling with substances, which when coagulated set an impermeable layer (this bonding is possible only when the disposal bowl in the course of storage is not filled with water),
- barrier of wells pumping polluted water back to the disposal, which is only partially effective.

The selection of a preventive method should be based on a cost benefit analysis.

F. In the openpits of the II-c type, one can store all kinds of coal wastes when the water protection is of the 2nd or 3rd degree. Due to the balanced hydrostatic head and no impact from the density difference of pure and polluted waters, there will be no significant vertical migration of pollutants. Such migration will take place only from dispersion. Within the aquifer these pollutants will occur exclusively in its upper-most part.

If the total disposal is filled with water, the recommended solution would be a clay sealing of the disposal bottom, by spreading clay on the surface of the water. The sinking clay would form an impermeable layer on the pit bottom. When the insulation treatment is to be made on a dry disposal, then impermeable sheeting or sprinkling with a sealing substance can be used.

G. In the openpits of the II-d type, the storage of coal wastes will always lead to pollution of groundwater. In the case of 1st degree protection of the groundwater, the disposal must always be insulated, no matter what type of coal waste is stored. Such an insulation may have a static character (sealing the floor and the slopes with impermeable sheeting or through sprinkling with a sealing substance), or a dynamic character (in a form of a barrier of wells barring the contact of polluted and pure waters). If in the course of sealing, the openpit is filled with water then there is no possibility to use the sheeting or sprinkling and only clay sealing may be employed. To meet 2nd degree requirements of groundwater protection and when there is waste material that is both permeable and nonpermeable, it should be stored selectively. The material less permeable (e.g., flotation silt) should be placed close to the slopes and the bottom of the disposal, and the coarse material in the disposal interior. This limits permeability of the disposal, thereby, limiting permeability of its outer layer. This in effect will allow smaller quantities of pure water to come into contact with the waste. Moreover, in this situation, the pollutants as a result of groundwater flow, will have a tendency to concentrate in the uppermost section of the aquifer.

XIII. When considering the relationship between the planned disposal site and the protected part of the aquifer the following applies:

- if the protected part of the aquifer is situated upstream of the groundwater flow, a 20-meter protection zone should suffice, since the dispersion influence will not exceed this limit,
- if the protected part of the aquifer is situated in the zone of indirect influence of the disposal, then such disposal can be planned without protection where the 2nd degree protection requirement applies. However, this is not acceptable when the 1st degree of protection is required,
- if the protected part of aquifer is located in the zone of direct influence of the disposal, i.e., downstream, then this disposal cannot be considered without providing protection, unless an appropriate model will indicate that this is permissible.

DESIGN OF MONITORING WELLS AND CONTROL PERFORMANCES

1. Monitoring of the disposal influence on groundwater quality can be performed through sampling and analyzing water from monitoring wells, or shallow probes, and from natural springs, where possible. There are no available remote sensing methods which would enable measurements of groundwater quality without direct access to them. However, some simple measurements could be made automatically in the wells (e.g., temperature, conductivity).

2. Depending upon local geological conditions and on requirements of the scope of inspection, there can be 1-3 monitoring pipes arranged in boreholes to sample different aquifers or for sampling different levels of the same aquifer. When more than one pipe is installed within a drilled well, total insulation is required.

3. When necessary (e.g. in case of aquifers of great thickness) to determine the contents of pollutants in vertical zones, then a single pipe monitoring well suffices for the zonal sampling. This should be used only when high precision is not required.

4. When disposal is totally insulated from the aquifer, the monitoring system should only determine the disposal's isolation. Wells should be spaced along its circumference. The wells' distance from the disposal verge should be not more than 20 m upstream, 30 m in the intermediate zone and 50 m downstream in the groundwater. The spacings between the wells should be smaller downstream, greater in the intermediate zone and greatest upstream. The respective numerical values can be a ratio of 1:3:5. Locating particular wells should be based on the analysis of effected sealing and on the hydrodynamic water heads' distribution.

5. Location of monitoring wells, where disposal will impact groundwater quality, should be based on the following:

   - the hydrodynamic water heads' network,
   - the spatial structure of the aquifer and its transmissivity,
   - the existence of flumes (lineaments) confirmed by remote sensing,
   - the reciprocal spatial relationship of the disposal and the protected zone.

   When the entire aquifer is to be investigated only a few wells may be located in the zone of indirect influence of disposal. Where the disposal is impacting downstream groundwater, the consecutive wells should be placed at distances gradually increasing i.e.:

   1st well 50 to 100 m from the edge of disposal site
   2nd well 100 to 300 m " " " " " "

3rd well 400 to 700 m from the edge of disposal site
4th well 800 to 1500 m " " " " " "

The wells in this direction should be located along the lines of a stream with the greatest hydraulic dipping or along the flumes (lineaments). The lines of monitoring wells (one to four) should be placed within an area encompassed by streams that could come in contact with the disposal. When controlling a specific part of the aquifer, the monitoring wells should be located along one or two lines between the disposal and the protected part. The lines should be located on the basis of hydrodynamic criteria or along the lineaments if any. Distances between the wells can be similar as on the previous example.

6. The monitoring wells should be drilled by the dry method, or by water washing. Drilling with the application of other fluid washings is inappropriate because it may lead to a colmatation of the zone near the well giving entirely erroneous conclusions. This results in groundwater flowing around the less permeable zone of the well, hindering the exchange of water between the well and the surrounding aquifer. The recommended filter diameter is from 4 to 6 inches.

7. In the course of drilling, the lithological log of all layers should be determined accurately. Levelling of the stabilized groundwater table, and tests to determine the permeability and the specific yield of all tested aquifers should be executed.

8. The water sampling from monitoring wells should be conducted after removal of 1-3 fold volume of water. Additional removal of water from the well can change the natural flow, whereas not removing the water may cause the sampled water to be in extended contact with air or with the well casing. The samples may be collected by way of pumping or manual scooping.

9. For the investigations of the unsaturated zone, and for the compacted rock material characterized by very fine pores, one may use (only in the course of drillings) soil or rock material samples taken for centrifuging to obtain micro-samples of water.

10. Transportation, preservation, fixing, and the method of analyses performed on water samples should meet the appropriate standards.

11. The water sampling connected with measurements of the water table position should be carried out with a recommended frequency:

    - Dry Type disposals, once a month
    - Wet Type disposals, every 3 months.

12. For Dry Type disposals, full analyses of groundwater should be made every 3 months (around 40 designations), and the remaining monthly analyses may be shortened (about 15-18 designations specified on the basis of filtrate analysis acquired in laboratory).

13. Due to the frequency (particularly in developed regions) of significant fluctuations of groundwater quality by various activities (e.g. fertilization, dust emission), it is essential to possess reference data, which can be:

    - a minimum one year cycle of the groundwater's analyses made prior to storage for the entire aquifer or;
    - when considering one part of the aquifer, using references from groundwater analyses from a part of the aquifer that does not undergo the influence of the disposal.

14. The results of groundwater tests should be periodically (minimum once a year) tabulated and discussed, to draw conclusions and to propose appropriate recommendations.

FURTHER RESEARCH

The most important problems to be solved in the next phase of research are:

1. Application of remote sensing (satellite and aerial photography) to determine the lineaments of migrating pollutants.
2. Investigation of a water balance for disposal for different types of waste and in various climatic conditions.
3. Investigation of flow of pollutants through the disposal itself and through the zone of aeration.

SECTION 4

PREVIOUS RESEARCH SUMMARY

This project was developed as a result of an earlier study published in a report entitled: "Effects of the Disposal of Coal Waste and Ashes in Open Pits".* Therefore it is necessary to present the results and conclusions from that study, which resulted in the scope and form of this project.

The aim of the first project was:

- to determine qualitatively and quantitatively the impact of coal refuse and ash storage on groundwater quality,
- to determine spatial and temporal interrelationships of the dispersion of pollutants,
- to suggest some improved methods of storage, and
- to prepare recommendations for tests, prognoses, and control systems.

The project was based on field investigations of test disposal sites, laboratory analyses of water and wastes and model tests.

The test site had a waste volume of 1500 m^3 and was located on a sand layer with a filtration coefficient about 50 m/24 hours. The groundwater table was a few centimeters below the sand surface, i.e. just under the bottom of the waste pile. The stored material consisted of 70 percent coal refuse, and 30 percent ash from a coal fired power plant. Within the disposal area and in its immediate vicinity, 12 monitoring wells were constructed.

Water samples from these wells were analyzed every three weeks for 15 months. The level of the water table was measured at the same time. Also, a comparative sample of groundwater was taken prior to entering the zone of disposal influence. These tests were then conducted at 6 week and 3 month intervals for the next 15 months. Throughout the test period, local precipitation was observed by a nearby hydrometeorological station. This was important because the waste was being leached by the rain water and the pollutants carried to the underlaying aquifer. In addition to the field tests, the wastes were leached in laboratory columns at optimum saturation conditions, with the object to obtain maximum possible concentrations of components in the leachate. All water samples were physico-chemically analyzed to obtain 17 parameters, and every third sample set was analyzed for 45 parameters, including heavy metals.

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* - Research and Development Series, EPA 600/7-78-067, April 1978

The first indications of pollution were found in the immediate subsoil of the disposal site after one month of storage. The major pollutants were found downstream in the groundwater after a heavy period of rain, about 7 months after storage.

Maximum increases in concentration of pollutants in the groundwater affected by disposal were as follows: TDS, 200 to 2000 mg/dm^3, sodium from 3.0 to 500 mg/dm^3, chlorides from 10 to 400 mg/dm^3, potassium from 2.0 to 40 mg/dm^3, magnesium from 10 to 30 mg/dm^3, sulphates from 100 to 900 mg/dm^3, phosphates from 0.05 to 0.3 mg/dm^3, boron from 0.2 to 2.0 mg/dm^3, molybdenum from 0.005 to 1.0 mg/dm^3, copper from 0.003 to 0.2 mg/dm^3, strontium from 0.07 to 0.4 mg/dm^3, cadmium from 0.002 to 0.005 mg/dm^3, cyanides from 0.002 to 0.008 mg/dm^3. No increase, however, was observed in the content of iron, manganese, aluminium or chromium. Increases in the content of zinc, mercury and lead were doubtful.

In general, during $2^1/2$ years 11,500 kg of pollutants, i.e. 0.7 percent of the disposal volume, and about 70 percent of all soluble substances were leached out of 1500 m^3 of waste.

The main bulk of the pollutants (90 percent) moved in the direction of the greatest gradient of the groundwater table, and only 10 percent in the direction of smaller gradients of the water table.

To investigate some aspects of the problem, which couldn't be determined in the field, a special research program was carried out on soil models and on analog models. It was found that:

- Within a 2 percent difference between the density of polluted water and pure water, no vertical migration of the polluted water had been found below the disposal site;
- The main migration occurs in the zone closest to the groundwater table and in the zone of capillary rise; this segregation is greater, the smaller the doses of polluted water reaching the groundwater table;
- If the disposal site is less permeable than the surrounding aquifer, the flume of pollutants leaving the disposal site has a tendency to narrow;
- Local depression of the aquifer floor increases the thickness of the pollution plume, while local elevations cause thickness reduction.

On the electrohydrodynamic (EHDA) analog model the main flumes of pollution in the aquifer and times of pollutants occurrence in particular wells around the disposal were predicted. From the above research recommendations in the following groups of problems were made:

a. Classification of the wastes,

b. Methods for laboratory analyses of wastes for preliminary evaluation of their impacts on groundwater,

c. Classification and evaluation of disposal sites,

d. Planning and designing of disposal sites,

e. Designing of monitoring systems and control work,

f. Directions of further studies for the ultimate solution of the problem.

The above analysis showed the need to continue the research on a full scale basis for a long period of time. Thus, the main goal of this work was to verify these results, conclusions and recommendations.

SECTION 5

DESCRIPTION OF THE DISPOSAL SITE

LOCATION

The test disposal site was located in an old sand pit situated in Boguszowice, about 200 km southwest of Wroclaw. The sand was exploited for backfilling of underground bituminous coal mines until 1969. The site comprises three pits which have the total capacity of about 3 million m^3. The main (central) pit had a capacity of about 1.5 mill.m^3, and has been abandoned for nearly six years. The western and eastern pits were smaller. 1975 coal wastes from a bituminous coal mine located in the vicinity have been disposed of in the pits.

The disposal site is situated on a morphological elevation. The natural surface elevation varies from 275 m to 280 m above sea level. The terrain slopes away in all directions (Fig. 5-1). One km to the east the land is about 255 m above sea level, and in the north the same elevation is observed at a distance of about 300 m from the disposal site. To the south and west the terrain declines gently and has respective elevations of 265 m and 275 m above sea level. The surrounding area is covered with meadows and arable fields, and at a distance of about 1 km toward the east there is a forest.

CLIMATE

Since the disposal site was located above the groundwater table, the amount of precipitation (which is the source of the aquifer recharge as well as the medium for pollutant leaching and transportation into groundwater) was of great importance in the investigation. The presentation of these data should be helpful for applying the research results to different or similar conditions in other regions of the world.

The average precipitation for the region during the investigated period was 788.0 mm and varied from 633.0 mm (in 1979) to 958.6 mm (in 1975). Daily and monthly precipitation values have been summarized in Tables 5-1 to 5-5. The highest monthly precipitation was observed in August 1977 (156.5 mm) and the lowest in February 1976 (3.6 mm). The maximum daily precipitation (62.5 mm) was observed in August 1975.

Less important but also significant is temperature which affects evaporation rates. The average daily air temperatures during the investigated period are provided in Tables 5-6 to 5-10. From the tables it can

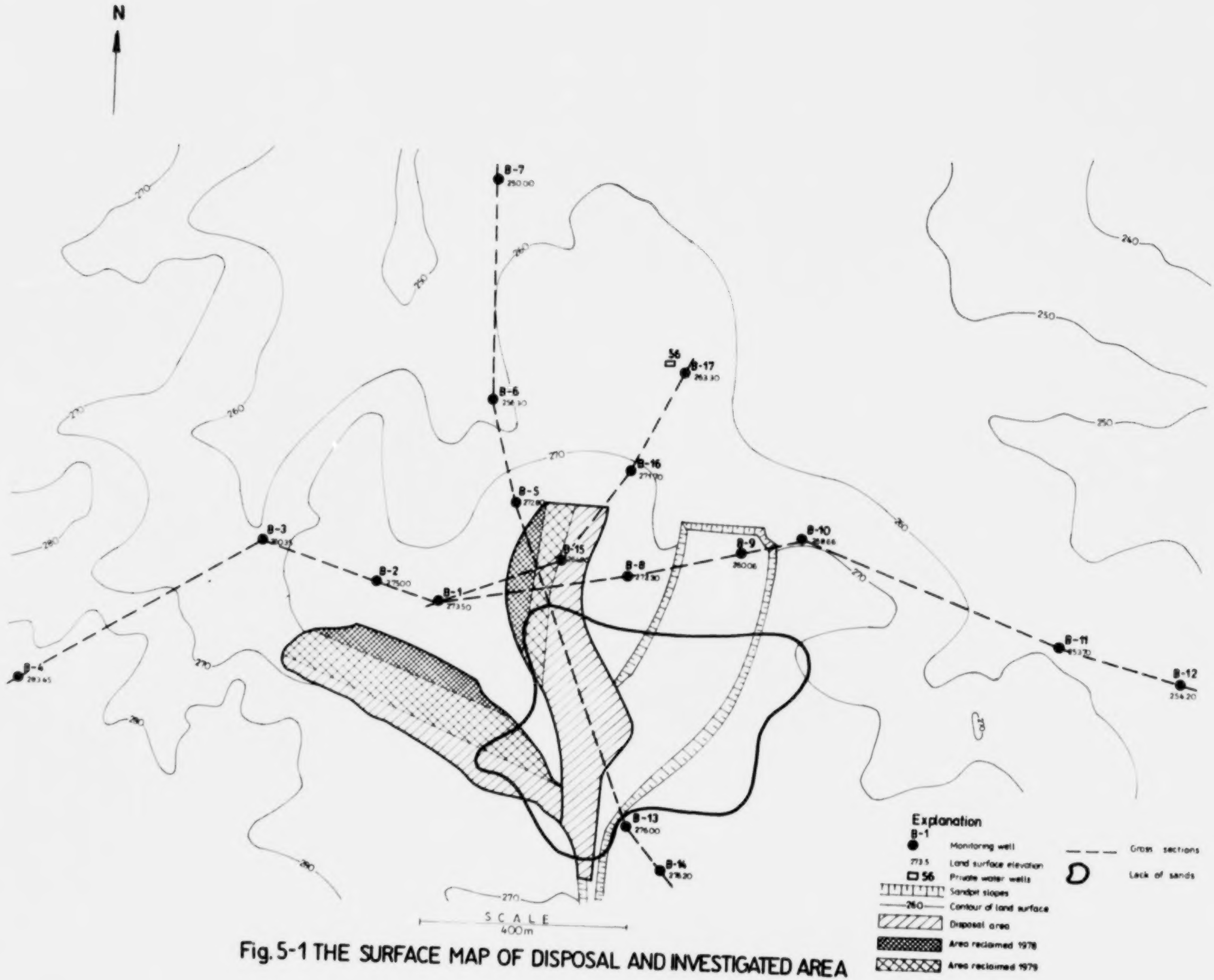

N
B-7
250.00
B-6
256.30
B-17
263.30
56
B-16
271.90
B-5
272.80
B-15
B-3
B-2
275.00
B-1
273.50
B-8
273.30
B-9
260.06
B-10
B-11
B-12
254.20
B-13
276.00
B-14
278.20
B-4
283.65
240
250
260
270
280
SCALE
400m
Explanation
B-1
Monitoring well
273.5
Land surface elevation
56
Private water wells
Sandpit slopes
260
Contour of land surface
Disposal area
Area reclaimed 1978
Area reclaimed 1979
Cross sections
Lack of sands

Fig. 5-1 THE SURFACE MAP OF DISPOSAL AND INVESTIGATED AREA

Table 5-1. The Daily and Monthly Sums of Precipitations (in mm)

Day	1 9 7 5											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	28.3	2,3	.	.	.	5,9	24,9	6,1	.	.	.	.
2	.	4,5	.	.	.	2,6	.	0,2	0,0	.	.	.
3	.	.	.	.	0,0	.	.	3,0	0,0	2,0	0,6	0,0
4	3,2	.	.	.	0,0	.	.	0,2	.	.	0,1	0,0
5	3,5	.	0,5	1,0	.	.	.	8,3	68,5	5,9	.	2,1
6	0,0	.	1,0	0,0	.	0,0	.	.	.	1,1	0,1	5,0
7	0,0	2,5	.	7,0	.	5,7	.	2,2	0,0	5,8	0,8	.
8	1,2	.	.	.	1,4	10,3	.	.	.	2,3	.	0,2
9	.	.	.	.	1,2	1,4	.	.	.	4,0	.	.
10	.	.	.	18,0	.	.	12,4	0,0	.	0,2	.	0,0
11	.	.	1,3	0,0	.	.	.	.	0,6	0,0	0,0	.
12	.	.	9,8	0,5	.	.	0,4	0,4	18,0	0,4	.	.
13	0,0	0,7	5,5	0,0	.	0,3	.	.	0,6	0,8	.	0,0
14	.	1,1	0,0	2,8	.	.	.	.	.	33,2	15,8	.
15	.	.	.	5,6	.	.	.	.	.	10,4	2,6	.
16	.	.	1,5	4,7	.	10,5	.	26,5	.	2,8	.	.
17	.	.	14,6	7,9	.	1,0	.	8,8	.	0,1	0,0	11,1
18	.	0,4	.	0,3	.	11,4	0,4	62,5	.	22,1	10,6	.
19	.	16,1	3,7	.	2,8	1,0	4,5	1,0	.	5,5	3,1	0,0
20	.	.	1,0	.	.	21,4	35,0	.	.	5,5	5,9	.
21	.	.	.	.	0,6	5,2	8,0	.	.	8,8	1,7	0,2
22	.	.	.	.	0,0	.	.	.	.	.	2,9	1,8
23	.	.	.	.	0,5	1,6	.	.	.	.	.	.
24	0,0	.	.	2,0	.	4,1	17,0	0,0	.	.	.	0,5
25	1,7	.	0,4	0,6	25,1	9,0	14,4	8,4	.	.	.	4,2
26	0,0	.	5,5	0,0	0,8	.	4,5	20,0	8,5	.	.	11,5
27	.	.	0,6	.	.	.	1,8	.	.	.	.	3,2
28	0,3	.	15,9	.	.	24,4	1,3	.	0,0	.	1,4	.
29	0,5	.	.	.	1,3	.	.	1,8	.	.	.	.
30	.	.	24,1	.	7,1	6,0	16,0	2,6	.	.	.	.
31	.		1,0		4,8		.	.		.		.
Monthly sum	38,7	27,6	86,4	50,4	45,6	121,8	140,6	152,0	96,2	110,9	45,6	42,8

Table 5-2. The Daily and Monthly Sums of Precipitations
(in mm)

Day	1 9 7 6											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	1,8	.	0,6	.	.	0,0	.	1,1	23,2	0,0	.	9,5
2	.	.	0,0	.	.	5,9	.	.	0,6	.	.	3,6
3	7,5	.	.	.	1,0	.	.	6,8	0,4	.	.	8,0
4	1,8	.	0,5	.	0,0	.	.	2,7	0,3	.	1,2	.
5	0,5	.	0,7	0,6	.	.	.	0,2	.	9,5	0,0	.
6	.	.	0,3	.	.	.	.	2,0	0,3	.	.	.
7	.	.	.	.	.	.	1,9	20,1	.	.	0,2	7,6
8	.	.	.	2,6	.	.	0,3	0,6	.	.	0,2	.
9	2,3	.	.	.	.	.	22,6	.	.	.	.	0,5
10	9,8	.	.	.	.	.	8,0	.	4,0	.	.	.
11	4,8	1,6	.	.	.	.	.	0,0	0,2	.	0,1	1,1
12	8,4	0,5	.	.	.	.	3,5	.	.	.	5,6	0,8
13	6,0	.	.	1,8	19,5	2,8	.	.	.	.	2,5	3,8
14	12,2	.	.	.	13,2	.	1,0	1,8	.	0,0	12,0	1,9
15	1,2	0,5	0,0	1,5	.	14,4	2,8	.	8,1	9,0	17,2	.
16	1,5	.	0,0	1,4	.	4,9	.	.	23,5	6,0	11,9	.
17	1,7	.	2,1	.	.	7,5	.	.	37,3	7,6	3,5	.
18	5,5	.	2,0	.	.	.	.	.	.	1,1	1,2	.
19	1,1	.	11,4	.	.	.	0,3	3,1	.	.	8,7	.
20	1,5	.	1,2	.	0,0	3,5	.	6,1	2,8	.	1,1	.
21	1,8	.	4,6	1,3	19,0	.	10,2	1,7	.	.	0,2	.
22	6,2	.	0,0	5,8	26,5	.	12,4	.	.	.	1,5	.
23	6,3	.	.	2,3	1,6	.	23,4	.	.	.	0,0	.
24	2,9	.	.	2,6	0,0	.	8,3	.	0,8	.	7,7	2,1
25	0,0	.	0,0	1,0	.	.	0,8	.	.	.	0,0	1,0
26	.	0,6	4,8	1,7	15,2	.	3,7	.	.	.	2,1	0,9
27	.	0,4	5,4	.	5,6	.	2,3	.	.	.	.	.
28	1,0	.	.	0,0	2,6	.	.	.	0,2	.	.	.
29	.	.	.	.	.	.	.	.	7,1	.	1,8	2,6
30	.	.	.	.	8,6	.	.	.	0,2	0,0	.	1,8
31	.		.		16,6	.	12,6	1,9	.	7,6	.	.
Monthly sum	85,8	3,6	33,6	22,6	137,4	39,0	114,1	48,1	109,0	40,8	78,7	45,2

Table 5-3. The Daily and Monthly Sums of Precipitations (in mm)

Day	1 9 7 7											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	.	.	0,4	.	.	.	.	27,9	.	7,3	3,8	3,1
2	.	.	3,6	.	0,0	5,3	.	32,5	.	2,3	1,2	2,1
3	13,1	.	8,4	.	.	.	.	2,4	.	3,0	10,4	0,5
4	.	.	2,5	.	.	1,1	.	1,5	.	.	0,2	.
5	.	1,1	3,5	.	0,5	0,0	.	1,6	.	.	.	.
6	.	5,9	1,9	.	14,9	1,4	5,2	.	.	.	.	.
7	2,8	3,5	.	11,1	9,9	1,0	.	.	0,4	.	.	.
8	1,8	2,4	0,0	18,6	.	.	.	.	13,0	.	.	.
9	.	0,5	.	17,7	.	.	0,2	15,8	5,2	.	6,4	4,0
10	.	7,0	.	0,4	.	.	16,9	3,9	0,0	2,7	1,8	.
11	.	1,5	.	.	3,9	.	1,3	.	4,6	1,6	.	.
12	.	12,6	.	.	.	.	.	.	.	.	3,2	.
13	13,5	4,6	8,4	5,0	0,0	.	0,4	4,1	.	.	.	0,6
14	3,3	.	0,5	0,0	6,2	2,2	11,7	0,0	.	.	0,6	1,6
15	6,1	16,5	.	.	4,1	.	1,6	.	12,4	.	.	.
16	.	0,0	.	1,4	.	.	.	.	3,3	.	3,4	.
17	1,1	.	.	.	.	.	.	.	.	.	0,5	.
18	.	.	.	.	.	1,0	0,0	3,6	16,2	.	0,7	.
19	.	.	.	.	.	8,9	4,5	18,0	0,9	.	.	.
20	1,4	0,5	1,1	.	.	7,8	3,2	3,0	.	.	.	.
21	.	10,3	0,9	0,0	.	.	29,9	21,7	31,4	.	0,5	.
22	.	7,3	.	0,9	.	.	.	5,3	12,6	.	0,0	.
23	0,5	14,4	.	1,6	1,7	.	.	15,2	0,7	.	.	.
24	2,5	.	.	3,0	.	.	.	.	.	.	.	1,7
25	4,1	14,9	.	3,6	.	.	0,1	.	.	0,2	.	5,3
26	2,8	3,6	0,4	.	.	3,0	.	.	.	.	1,7	2,2
27	.	1,7	2,3	2,0	.	.	.	.	.	.	.	4,2
28	.	4,0	18,1	.	.	.	.	.	.	.	1,0	.
29	13,2	.	2,9	.	.	.	.	.	.	.	.	0,0
30	7,5	.	5,6	.	14,5	1,9	35,6	.	.	5,4	2,1	2,8
31	.	.	2,4	.	3,7	.	14,0	.	.	.	-	4,0
Monthly sum	73,7	112,3	62,9	65,3	59,4	33,6	124,6	156,5	100,7	22,5	37,5	32,1

Table 5-4. The Daily and Monthly Sums of Precipitations (in mm)

Day	1 9 7 8											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	0.0	.	.	.	14.6	.	6.5	.	0.8	6.4	.	.
2	0.4	.	.	1.9	0.4	.	1.1	.	4.8	.	.	.
3	0.5	.	.	0.0	0.3	.	0.5	.	2.8	.	.	.
4	.	0.3	.	.	.	.	5.1	0.7	0.6	8.1	.	.
5	0.2	.	1.4	.	0.4	13.6	15.5	0.5	.	0.2	.	0.3
6	5.3	.	1.2	.	.	.	4.5	.	.	3.0	.	0.1
7	0.6	5.7	.	.	8.8	1.1	0.6	11.3	3.8	.	.	.
8	.	4.6	1.2	.	.	2.4	14.5	32.1	2.3	.	.	.
9	.	0.3	9.1	.	1.2	3.0	5.3	20.2	2.0	.	.	6.1
10	.	.	3.1	0.3	0.3	2.1	6.6	6.1	19.2	.	.	2.6
11	.	.	0.0	.	2.5	.	.	2.6	8.3	.	.	.
12	.	3.4	0.0	7.2	.	1.8	4.8	.	12.6	.	.	0.2
13	0.0	.	2.3	18.6	0.2	0.6	0.1	.	.	.	.	.
14	0.4	.	.	2.0	.	5.0	1.6	.	8.6	.	.	0.2
15	.	0.9	.	.	.	.	.	.	0.2	.	.	.
16	.	2.0	2.9	.	3.9	.	.	.	.	.	0.0	0.2
17	.	.	3.7	0.3	3.8	2.8	.	19.1	.	.	.	0.2
18	.	.	0.3	0.3	.	.	.	15.1	.	7.7	.	.
19	.	.	.	1.6	.	.	0.0	15.8	1.1	6.8	.	.
20	.	.	1.3	7.6	.	.	0.9	0.7	1.6	0.7	.	6.3
21	.	.	2.0	0.3	0.8	2.9	2.8	.	2.1	0.6	.	.
22	.	.	0.5	0.0	7.3	0.8	.	.	11.2	5.6	.	.
23	.	.	0.9	2.1	3.2	0.3	.	19.8	5.5	2.3	.	.
24	0.6	.	0.9	0.0	12.1	13.1	.	0.5	1.3	.	.	.
25	1.7	.	.	0.3	4.2	1.9	.	0.6	.	12.8	.	.
26	0.0	.	.	.	0.5	7.8	.	.	0.5	0.5	2.7	.
27	0.4	0.0	.	.	12.5	0.2	.	0.0	0.0	.	11.8	2.9
28	.	.	0.3	0.0	1.1	.	.	.	0.8	4.7	0.7	3.0
29	0.4	-	.	1.5	11.2	.	.	.	1.3	2.8	15.1	6.3
30	.	-	.	5.6	.	.	.	3.0	2.0	0.9	12.1	2.8
31	0.0	-	.	-	.	-	.	.	-	.		4.0
Monthly sum	10.5	17.2	31.1	49.6	89.3	59.4	70.4	148.1	93.4	62.6	42.4	35.2

Table 5-5. The Daily and Monthly Sums of Precipitations (in mm)

Day	1 9 7 9											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	1.7	.	0.8	.	0.0	.	0.7	.	.	.	1.3	6.7
2	3.0	1.5	0.2	.	13.2	.	.	.	.	.	3.5	.
3	3.5	.	.	.	5.4	.	.	1.3	0.8	.	.	.
4	1.5	.	3.0	0.6	.	.	.	12.3	5.9	.	.	.
5	0.6	4.2	0.0	4.5	7.9	.	0.8	.	0.5	0.9	0.5	0.9
6	.	.	.	14.0	0.3	.	2.9	.	.	.	1.6	.
7	.	2.4	6.6	6.8	.	0.4	6.0	0.0	.	.	0.7	0.9
8	.	3.5	2.5	0.3	.	0.0	9.5	1.2	.	.	0.3	1.2
9	4.7	.	.	.	7.9	.	2.4	4.2	2.3	.	0.2	0.9
10	0.0	.	3.8	.	.	.	.	5.9	.	.	0.6	12.3
11	11.5	2.8	0.4	.	.	.	.	.	.	.	2.0	4.6
12	.	6.3	3.5	.	.	8.9	.	0.1	.	.	1.6	1.0
13	.	0.2	2.1	.	.	.	.	0.8	.	.	0.3	.
14	2.7	.	1.2	.	.	13.5	.	.	4.2	.	0.7	6.5
15	5.8	3.0	.	.	.	0.0	0.6	.	2.8	.	1.1	3.8
16	1.6	2.4	9.6	.	.	3.9	2.1	.	.	.	6.1	.
17	.	1.3	5.2	6.7	.	7.4	0.4	.	.	13.0	9.1	5.7
18	0.7	0.3	0.2	0.3	.	1.8	.	.	.	3.7	5.3	0.8
19	.	.	1.1	0.0	.	0.3	5.8	4.8	.	1.3	3.4	0.3
20	5.5	.	0.0	.	.	.	.	0.3	.	.	0.5	3.1
21	6.7	.	.	0.3	0.9	1.1	.	.	0.5	0.6	0.4	1.3
22	.	.	2.0	.	.	0.0	.	.	0.0	8.1	.	.
23	.	.	.	.	.	0.0	.	.	4.8	.	.	.
24	8.4	1.3	.	0.4	.	0.0	2.6	8.5	15.0	.	.	4.5
25	.	2.8	.	2.9	23.9	0.0	9.1	7.4	0.7	.	.	1.1
26	.	.	0.1	0.2	0.2	3.0	1.3	3.6	.	.	2.1	.
27	.	.	3.5	6.7	.	.	0.6	0.5	.	.	0.3	.
28	9.7	0.1	.	5.2	1.7	2.9	.	.	0.7	.	6.6	.
29	12.4		7.6	1.2	.	.	1.7	1.0	.	9.5	4.6	3.5
30	2.3		1.3	5.0	.	.	5.5	.	.	0.4	3.8	.
31	3.0		6.3		.		.	.		.		.
Monthly sum	85.3	32.1	61.0	55.1	61.4	43.2	52.0	51.9	38.2	37.5	56.3	59.1

Table 5-6. The Average Daily Temperatures (in centigrades)

Day	1975											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	1,2	1,9	3,0	1,8	10,1	7,3	12,4	18,2	19,6	19,4	3,7	4,6
2	3,0	3,6	5,2	4,5	11,2	6,6	19,8	16,4	20,1	15,8	4,6	5,8
3	3,4	0,4	7,4	5,8	10,3	11,7	20,2	16,7	20,0	15,4	7,7	4,4
4	2,1	-2,5	6,2	9,2	8,8	12,8	20,0	18,5	19,5	13,3	7,6	4,4
5	3,8	-3,3	9,1	13,3	11,0	11,3	20,4	16,4	17,7	10,0	7,6	2,9
6	6,1	-2,9	7,2	13,5	14,8	10,8	20,3	19,1	14,8	12,3	6,9	4,1
7	5,8	-2,4	7,8	8,1	18,2	12,6	19,6	20,6	15,1	11,0	6,5	0,9
8	0,3	-2,2	8,0	7,5	18,1	12,2	20,0	21,2	13,0	8,5	7,0	2,4
9	-1,4	-3,6	9,8	7,2	14,7	14,8	21,4	22,0	11,4	6,7	4,0	2,6
10	1,6	0,1	11,5	6,2	14,6	16,2	21,4	20,7	15,1	5,0	2,6	1,5
11	4,4	1,7	10,2	3,2	14,7	17,2	20,7	21,6	16,0	4,0	0,8	-0,4
12	5,5	4,0	8,6	3,1	15,8	18,7	21,1	21,0	13,9	3,0	0,9	-1,8
13	5,2	3,6	6,2	4,2	12,1	20,2	20,4	15,6	11,8	6,9	1,7	0,8
14	5,0	3,4	4,5	4,6	18,1	18,3	22,9	14,6	14,6	10,0	3,5	-0,1
15	5,1	-1,7	6,6	9,8	19,4	21,6	24,0	16,8	17,4	4,8	3,0	-3,4
16	5,0	-5,5	7,0	9,5	16,1	21,5	23,7	19,4	18,6	9,5	3,1	-2,5
17	4,1	-5,9	1,6	5,3	18,2	14,3	20,0	20,1	19,4	8,7	2,2	0,1
18	5,1	-1,1	1,4	5,2	18,3	13,8	18,4	17,7	20,2	7,8	7,9	-5,3
19	6,0	0,1	5,2	6,4	20,4	15,5	18,3	16,5	18,0	8,6	4,9	-11,9
20	5,2	0,1	6,2	7,2	15,9	19,1	15,6	17,2	16,8	6,8	3,2	-3,2
21	3,6	-0,5	-0,3	7,7	15,2	19,4	15,3	17,7	16,2	8,0	0,4	-1,6
22	3,2	-5,0	-0,2	7,8	12,9	20,7	18,0	18,7	15,8	9,8	-0,4	2,3
23	2,8	-2,4	1,5	8,2	9,4	20,5	20,5	19,1	14,7	10,6	-2,6	2,4
24	4,8	1,9	1,0	9,9	11,2	21,8	20,7	16,4	17,4	8,0	-3,9	2,0
25	4,0	-0,4	2,2	6,0	11,5	19,6	13,5	17,8	16,4	3,8	-8,4	1,7
26	4,3	-1,6	1,5	5,8	11,4	18,7	12,6	16,2	18,2	3,2	-9,8	0,1
27	1,4	-0,4	2,1	7,7	13,5	19,8	14,3	17,2	14,9	5,4	-5,9	4,0
28	0,2	0,8	7,4	9,0	16,0	16,7	14,2	16,0	18,8	4,8	1,4	2,9
29	1,2		4,1	13,0	17,2	12,9	20,2	17,2	19,2	6,4	5,0	2,7
30	1,4		2,8	12,6	15,2	13,2	18,6	18,1	18,8	8,1	5,2	-0,7
31	2,2		1,1		10,9		18,7	19,0		5,1		0,1
Monthly average	3,4	-0,7	-5,0	7,4	14,4	16,0	18,9	18,2	16,8	8,4	2,3	0,7

Table 5-7. The Average Daily Temperatures (in centigrades)

Day	1 9 7 6											
	Jan	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	1,7	-8,4	5,2	11,8	7,2	10,7	20,8	14,8	16,7	8,7	5,4	7,9
2	2,0	-7,0	3,4	12,4	9,6	11,0	19,7	14,1	15,8	10,6	6,1	6,2
3	3,3	-8,5	0,5	15,2	13,2	11,3	20,6	14,5	12,6	14,1	7,4	2,3
4	-0,5	-2,8	-2,7	12,5	14,6	9,6	22,0	14,5	11,4	16,1	9,4	1,2
5	-2,8	-1,6	-5,6	12,4	14,0	13,0	18,8	14,0	11,5	13,5	10,4	-0,9
6	0,7	-5,6	-3,4	12,4	13,8	14,2	15,6	14,4	11,0	12,8	12,1	0,7
7	-2,1	-5,3	-4,6	7,0	14,4	17,2	17,0	13,8	13,9	15,0	12,1	3,9
8	1,2	-7,2	-4,1	4,0	14,1	18,1	17,0	14,4	16,0	15,6	9,4	4,9
9	2,7	-4,6	-1,5	4,0	16,4	14,9	16,0	15,6	15,8	14,6	8,9	4,6
10	2,6	-3,4	-3,0	3,8	17,1	12,7	14,1	17,8	14,8	15,3	10,0	2,8
11	3,5	-2,1	-4,8	4,8	17,4	14,4	17,4	17,5	11,3	15,9	14,3	0,7
12	6,1	-2,8	-3,9	6,4	16,7	15,8	20,0	17,0	14,2	15,6	10,5	-0,6
13	2,6	-4,2	-1,2	8,5.	14,7	16,4	21,3	16,6	17,0	17,2	8,2	-1,2
14	-0,3	-1,4	0,3	9,6	7,6	14,2	20,4	14,2	19,8	15,8	7,1	-2,0
15	-0,4	1,1	1,4	7,4	9,3	16,2	19,4	15,6	13,0	11,7	5,0	-3,2
16	-5,7	-0,2	3,8	9,8	13,2	11,8	20,7	16,2	13,6	6,7	3,2	-4,0
17	-2,0	-1,7	2,6	10,7	14,4	11,9	22,6	17,0	11,7	1,6	3,2	-5,6
18	-3,8	-1,6	0,1	11,4	16,2	17,2	25,0	14,8	11,4	2,8	3,3	-3,8
19	1,0	1,3	-0,1	12,5	16,2	20,0	25,6	14,3	11,4	4,8	2,9	2,1
20	2,0	2,0	-3,9	11,2	16,5	21,0	24,5	14,6	9,3	4,8	1,7	2,8
21	3,2	1,2	-5,3	8,0	14,9	20,1	22,7	13,2	10,1	1,3	2,1	1,4
22	1,7	0,2	-4,1	3,0	10,1	18,8	16,9	13,0	10,0	5,4	2,0	2,4
23	3,2	0,0	-4,1	2,0	12,1	18,4	15,5	13,4	12,2	7,5	-0,6	1,7
24	-0,4	-1,2	-2,6	6,3	10,4	18,5	14,8	14,0	11,5	4,7	0,0	-1,2
25	-3,9	-0,4	1,4	6,3	15,4	19,7	14,4	17,0	12,0	5,6	-2,3	-3,4
26	-4,4	4,2	5,0	5,6	16,6	20,0	18,2	18,6	7,8	6,1	0,0	-6,0
27	-7,0	5,6	5,1	6,9	12,4	21,8	17,6	19,2	9,2	7,2	3,2	-5,8
28	-7,5	4,6	4,8	2,1	11,8	22,5	18,2	18,6	15,2	1,2	3,8	-4,0
29	-8,3	5,7	8,8	1,6	11,9	22,6	15,2	19,5	17,1	7,9	4,1	-4,9
30	-7,6		8,9	4,3	13,4	21,2	17,6	19,4	12,6	11,4	5,3	-6,5
31	-6,0		8,2		11,8		19,5	18,9		9,5		-7,0
Monthly average	-0,9	-1,5	0,1	7,8	13,5	16,5	19,0	15,8	13,0	9,7	5,6	-0,4

Table 5-8. The Average Daily Temperatures
(in centigrades)

Day	1977											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	-3,7	-4,5	-1,0	1,6	20,2	7,6	17,0	15,4	20,8	11,6	6,8	-0,9
2	-0,2	-3,8	0,8	8,0	17,7	7,1	16,6	14,0	18,8	9,3	7,2	-2,4
3	1,6	-5,3	3,8	10,0	19,9	9,3	18,6	14,8	19,0	7,6	8,2	-2,8
4	1,2	-4,1	7,1	7,2	21,1	12,0	17,7	16,6	17,8	9,2	13,2	-5,0
5	-0,1	0,1	5,2	4,4	21,0	13,9	16,6	18,2	16,5	12,2	10,2	-2,6
6	-1,3	1,9	5,8	6,3	12,0	14,2	14,8	19,7	17,8	12,1	9,1	-4,8
7	-1,1	3,2	4,2	8,0	8,9	17,0	17,8	19,2	18,7	14,7	9,4	-3,3
8	-1,3	5,4	5,2	2,4	7,7	20,1	17,6	20,0	17,2	16,5	8,0	-3,6
9	-3,6	2,4	8,4	0,3	8,9	21,4	17,7	18,7	12,4	16,0	9,4	-0,4
10	-0,8	1,5	8,1	-0,4	11,5	23,4	15,8	18,1	10,4	14,8	9,3	-3,7
11	3,4	5,4	7,7	-0,3	10,4	23,6	17,4	17,5	11,2	12,8	12,2	-5,4
12	5,8	5,2	10,9	0,2	15,3	20,8	18,4	17,0	18,1	10,8	12,9	-5,2
13	1,3	2,0	8,4	3,9	15,8	22,3	20,4	16,0	11,7	10,7	6,9	-2,8
14	-1,2	0,8	8,4	5,4	12,4	22,8	19,0	17,0	9,2	9,7	3,8	-1,0
15	1,3	-0,2	8,5	4,0	11,8	20,0	13,9	15,9	11,6	7,4	6,6	1,7
16	0,2	-0,2	6,2	3,7	11,2	20,8	15,2	13,6	7,9	5,2	5,2	1,4
17	-2,6	-1,0	8,8	5,2	9,4	21,6	16,1	13,4	7,8	6,3	3,9	0,2
18	lack of data	-1,0	8,8	5,2	11,2	21,9	17,8	17,1	6,8	9,6	3,0	-2,5
19		5,5	9,2	3,6	13,4	19,4	16,8	16,2	6,8	10,6	3,0	-3,4
20		8,3	8,7	4,3	21,4	16,6	18,3	14,9	8,0	7,8	3,0	-2,6
21		9,0	9,3	7,9	15,2	17,2	14,8	16,6	9,0	7,1	4,4	-1,5
22		7,2	10,0	12,0	8,4	17,1	15,0	15,0	8,3	8,5	5,4	-1,3
23		3,9	10,0	13,2	9,3	17,6	16,4	11,7	10,1	11,6	3,5	-1,2
24		6,2	11,6	10,6	11,7	18,2	18,8	12,9	9,2	11,8	4,8	0,2
25		4,4	10,7	5,5	13,1	20,4	23,2	13,8	6,2	12,0	4,7	4,3
26		3,4	9,3	8,7	7,4	19,0	16,4	14,7	6,2	11,5	0,9	2,8
27		-2,7	8,4	11,1	8,9	15,7	16,5	17,4	4,8	10,4	1,5	3,9
28		-4,7	10,1	10,7	11,3	15,4	17,4	16,8	5,2	8,9	-0,8	3,6
29			-0,7	16,2	14,7	17,1	18,9	17,1	8,1	11,1	-1,3	2,6
30			-2,8	21,4	14,1	15,2	19,2	19,1	12,5	10,1	-2,6	1,9
31			-2,0		7,2		16,1	20,7		9,2	-	-0,2
Monthly average	-	1,7	6,7	6,7	13,0	17,6	17,3	16,5	11,6	10,6	5,7	-1,1

Table 5-9. The Average Daily Temperatures
(in centigrades)

Day	1978 Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	-1.2	0.8	7.2	11.6	10.4	18.6	17.7	21.6	10.9	9.6	8.5	0.5
2	1.8	1.6	6.4	10.5	10.8	19.1	15.0	22.1	10.6	9.0	5.2	0.7
3	3.3	-0.7	6.2	9.3	8.2	19.5	16.7	19.8	10.6	10.8	4.8	-0.8
4	1.8	-3.4	7.1	8.1	10.4	19.2	19.2	20.9	11.4	13.8	6.2	-8.1
5	-3.3	-4.7	8.5	5.6	13.5	18.6	14.2	20.1	13.4	8.2	5.8	-10.9
6	-4.6	-2.9	3.4	1.3	15.3	19.3	14.2	18.4	13.6	10.9	5.6	-8.6
7	0.8	-3.6	0.9	2.2	14.6	19.6	15.4	20.0	14.8	13.2	5.4	-13.0
8	0.8	-5.1	2.7	4.0	12.4	20.4	13.4	20.5	12.2	12.3	5.4	-12.4
9	-3.0	-6.3	4.0	3.8	10.7	17.4	13.3	12.6	13.0	13.1	3.5	-6.6
10	-3.4	-7.3	3.4	7.4	5.2	16.8	11.8	14.9	13.8	13.9	2.2	1.8
11	1.0	-1.4	5.0	10.1	1.7	13.6	15.6	14.6	19.2	12.5	1.2	2.3
12	3.4	1.[illegible]	1.1	3.8	3.4	12.6	17.2	13.4	12.5	13.2	0.2	2.2
13	1.4	-3.0	2.2	0.6	5.2	11.4	17.6	14.5	11.0	11.3	-0.7	4.9
14	0.2	-5.8	6.0	1.1	9.2	12.0	17.2	15.8	13.0	11.8	0.3	4.8
15	-0.8	-2.4	7.8	2.9	9.8	12.6	14.3	17.5	13.8	12.0	2.2	4.9
16	-2.8	-2.8	8.4	2.0	10.2	14.2	13.2	19.5	12.8	10.6	1.3	4.7
17	0.9	-4.9	5.8	3.4	11.0	12.2	14.3	18.5	15.2	9.8	2.0	-2.0
18	-0.5	-4.8	1.1	5.0	12.2	12.2	15.6	13.0	13.0	8.6	5.1	-5.5
19	0.0	-7.3	2.0	3.7	13.8	13.6	16.1	12.6	11.6	8.4	2.5	-6.9
20	-3.8	-9.9	2.4	5.0	15.1	16.9	15.8	13.2	7.6	6.2	0.8	-3.0
21	-6.8	-6.6	1.3	8.1	16.8	17.4	14.0	15.4	8.2	5.0	2.9	-1.9
22	-4.6	-3.8	-1.2	9.0	16.4	17.5	12.4	16.6	10.2	4.7	3.8	-4.4
23	-2.2	1.3	1.2	10.4	17.6	17.7	13.5	18.5	12.2	7.1	7.2	-3.5
24	1.2	2.8	4.8	10.1	12.6	13.8	14.8	16.9	11.7	8.6	7.6	1.3
25	2.6	7.6	4.3	9.6	14.5	14.8	17.1	15.0	17.1	8.6	5.0	2.4
26	1.8	9.7	4.6	8.1	11.0	12.8	19.0	12.9	12.8	5.9	0.6	3.2
27	1.0	5.6	4.5	9.6	12.5	13.6	20.4	11.8	11.1	2.5	0.1	4.5
28	2.2	5.7	6.4	10.8	14.6	11.9	21.4	11.9	8.8	3.1	-0.4	4.0
29	6.8	-	11.3	10.5	15.2	13.8	21.1	13.4	7.9	7.9	-0.1	8.2
30	3.8	-	12.4	9.5	17.0	17.0	20.9	14.3	12.2	9.1	0.2	-2.2
31	0.6	-	14.8	-	18.3	-	21.2	10.8	-	9.2	-	-4.8
Monthly average	0.0	-1.8	5.0	6.6	11.9	15.7	16.2	16.2	12.2	9.4	3.2	-1.4

Table 5-10. The Average Daily Temperatures (in centigrades)

Day	1979											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	-17.0	0.1	-0.4	4.5	6.1	23.4	13.6	22.4	18.0	6.2	-0.6	8.3
2	-10.8	2.5	2.8	5.6	7.5	24.0	13.8	24.0	18.5	4.8	0.1	7.6
3	- 9.5	0.2	3.4	6.8	5.3	23.3	14.4	20.6	19.1	4.4	0.0	6.8
4	- 9.6	-0.6	6.0	8.7	6.6	22.0	15.9	17.7	14.8	6.0	0.2	8.0
5	- 9.6	-1.4	3.2	5.6	8.3	21.7	15.0	16.4	13.6	10.2	2.8	7.1
6	-10.3	-1.1	0.7	3.5	6.8	21.9	17.0	16.8	14.3	4.5	5.1	7.6
7	-10.4	-3.5	4.2	1.6	8.0	21.0	14.3	19.1	13.8	6.8	5.0	5.8
8	- 3.2	-2.2	3.7	1.3	10.2	17.7	13.1	21.3	15.6	9.0	5.4	8.6
9	- 2.6	-2.8	1.6	3.2	8.0	18.5	14.2	18.2	16.4	9.3	16.4	8.2
10	- 1.7	-6.3	2.2	6.3	11.1	19.0	14.5	17.4	15.9	9.0	4.5	9.0
11	- 1.7	-7.4	1.4	5.4	10.5	19.9	14.7	15.8	16.1	10.8	2.6	8.8
12	- 1.1	-1.9	3.4	7.2	11.0	17.7	15.5	14.6	15.6	14.9	1.0	0.0
13	- 1.9	0.5	5.2	10.4	13.0	19.6	18.5	13.1	17.0	16.3	2.0	-4.3
14	- 4.5	0.4	3.9	12.5	16.0	16.5	19.7	15.8	15.1	15.8	4.6	-3.8
15	- 3.1	1.8	2.4	12.0	14.6	16.6	18.0	19.2	11.7	18.4	9.2	1.6
16	- 1.7	-4.7	8.1	7.2	18.0	16.2	14.5	20.4	8.1	15.8	8.9	3.6
17	- 3.5	-4.8	4.7	8.2	20.6	14.5	13.1	19.8	10.0	12.7	4.0	3.7
18	- 4.6	-2.2	2.6	2.0	21.2	12.8	15.5	18.6	16.3	10.2	5.1	5.1
19	- 4.2	-1.9	2.8	2.6	22.0	16.2	19.8	16.8	18.3	7.7	5.2	2.3
20	- 5.4	-3.3	5.4	4.7	22.1	16.9	17.9	16.9	18.3	9.1	3.8	-0.1
21	- 5.5	-4.2	9.7	8.6	23.6	15.9	17.7	16.9	16.0	8.7	4.2	0.4
22	- 4.5	-4.6	7.4	9.4	19.4	14.9	16.4	18.3	11.7	6.2	3.2	0.8
23	- 2.8	-4.5	6.2	11.3	20.6	18.8	14.1	20.5	11.5	3.6	2.9	8.6
24	0.4	-3.6	3.4	13.5	22.2	21.8	14.2	18.8	10.8	1.3	2.4	4.1
25	- 1.2	-2.4	4.4	11.2	19.3	22.0	13.8	12.8	9.0	0.9	1.2	4.3
26	- 3.7	-3.4	8.9	10.8	15.7	19.1	15.0	13.7	10.6	0.0	0.7	2.6
27	1.3	-4.7	9.2	9.0	20.0	21.9	13.4	13.7	11.4	-0.1	4.7	0.2
28	2.9	-4.2	8.4	7.7	16.0	18.2	16.0	13.0	9.8	0.4	3.4	-0.8
29	0.2		10.0	6.9	16.0	17.5	17.6	11.6	10.8	0.5	6.1	1.4
30	- 0.4		6.6	10.9	17.7	16.5	20.2	13.8	6.3	1.6	9.1	0.2
31	0.6		3.1		22.8		20.9	15.6		-0.4	-	-0.7
Monthly average	- 4.2	-2.5	4.7	7.2	14.9	18.8	16.0	17.2	13.8	7.2	3.8	3.7

be seen that the highest average monthly temperature was + 19°C and was recorded in July 1976, while the lowest monthly temperature was -4.2°C and was observed in January 1979. The highest average temperature for 24 hours was 25.6°C, while the lowest was -17.0°C. The average yearly temperatures were from + 7.8°C (in 1978) to + 9.2°C (in 1975).

The above characteristics show that the disposal site under investigation was located in a moderate climate typical for Central Europe and the Central and Northern United States. However, the influence this climate exerts on the research is comparable to the influence of climatic conditions on other areas.

GEOLOGY AND HYDROLOGY

Geological and hydrological conditions at the disposal site were described from 13 wells drilled in 1974 and 3 wells drilled in 1976 and 1977. The three new wells did not introduce any changes to our knowledge of geological and hydrological conditions and their goal was to improve the monitoring network only. All geology and hydrology are illustrated in Figs. 5-2 to 5-4. The geologic structure of the study area include Carboniferous, Tertiary and Quaternary formations and are described below:

Carboniferous Formation

The Carboniferous formation is represented by tectonically disturbed shales and sandstones with coal deposits in the Upper Carbon area. This formation with a thickness of a few thousand meters, was not encountered in the investigated area by the drilled wells, as it occurs at a depth of over 100 m. Carboniferous layers are characterized by irregular water bearing capacity dependent on the lithology and on fissures. The rocks and waters of this horizon are characteristically saline. The Carboniferous aquifer has no great importance to this study because of its great depth and lack of direct contact with the waste. However, the salinization of the rocks and groundwater within the mine affects the character of the refuse. This factor is discussed in Section 6.

Tertiary Formation

The Tertiary formation laying directly over the Carboniferous formation is composed mainly of clays containing small deposits of sand and gypsum. The thickness of this formation varies from 50 to 150m. The tertiary aquifers exist in small sand deposits with little horizontal and vertical spreading. Consequently, this aquifer has a discontinuous character, with groundwater found in closed reservoirs with only static resources, and has no contact with the waste.

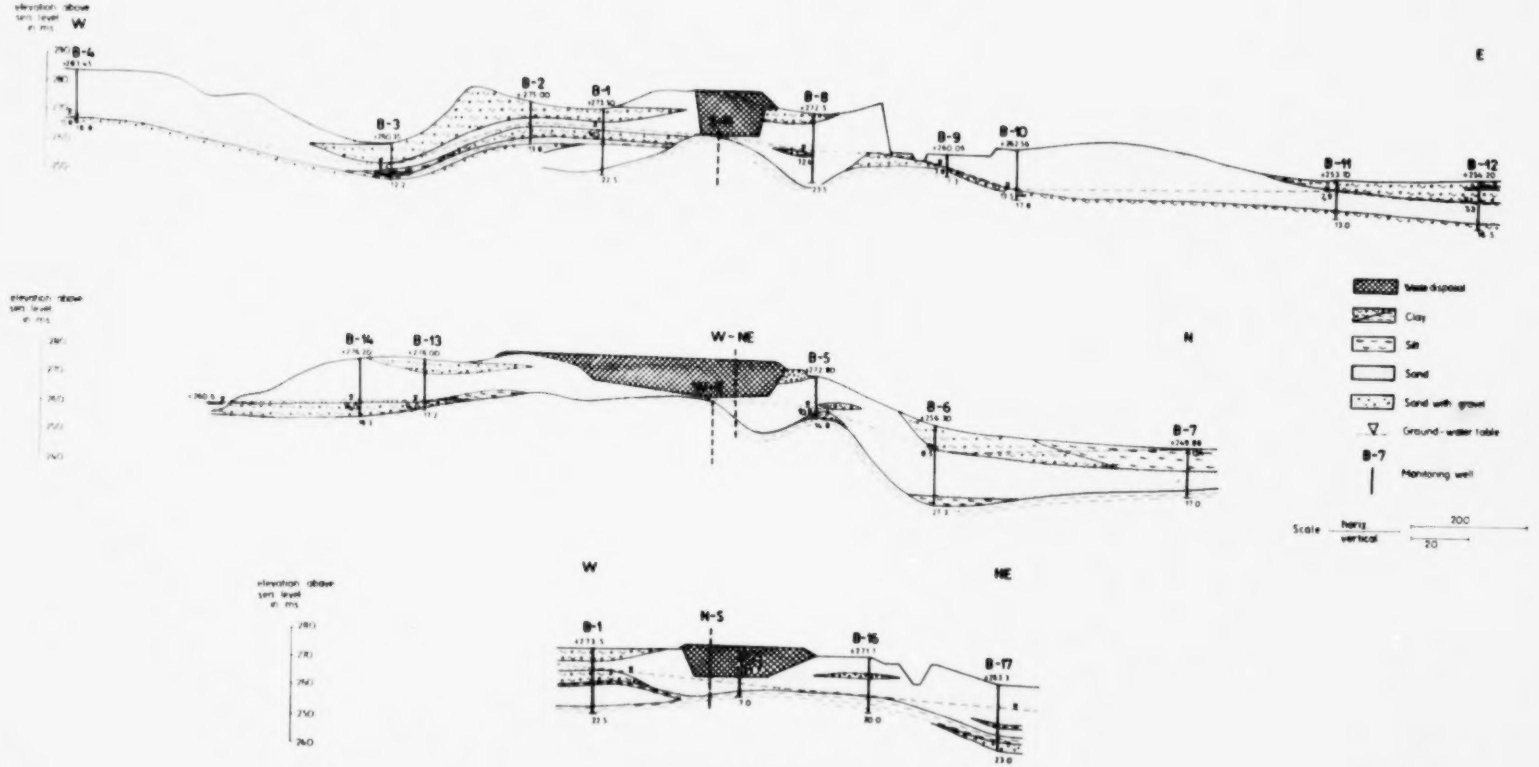

elevation above sea level in ms
W
E
B-4
+281.41
B-3
B-2
+275.00
B-1
+273.50
B-8
+272.5
B-9
+260.06
B-10
+262.36
B-11
+253.10
B-12
+254.20
22.5
23.5
13.0
elevation above sea level in ms
W-NE
N
B-14
B-13
B-5
+272.80
B-6
+256.10
B-7
+249.88
+260.5
21.3
17.0
W
NE
elevation above sea level in ms
280
270
260
250
240
N-S
B-1
+273.5
B-16
B-17
22.5
7.0
20.0
23.0
Waste disposal
Clay
Silt
Sand
Sand with gravel
Ground-water table
B-7
Monitoring well
Scale
horiz.
vertical
200
20

Fig.5-2 HYDROGEOLOGICAL SECTIONS

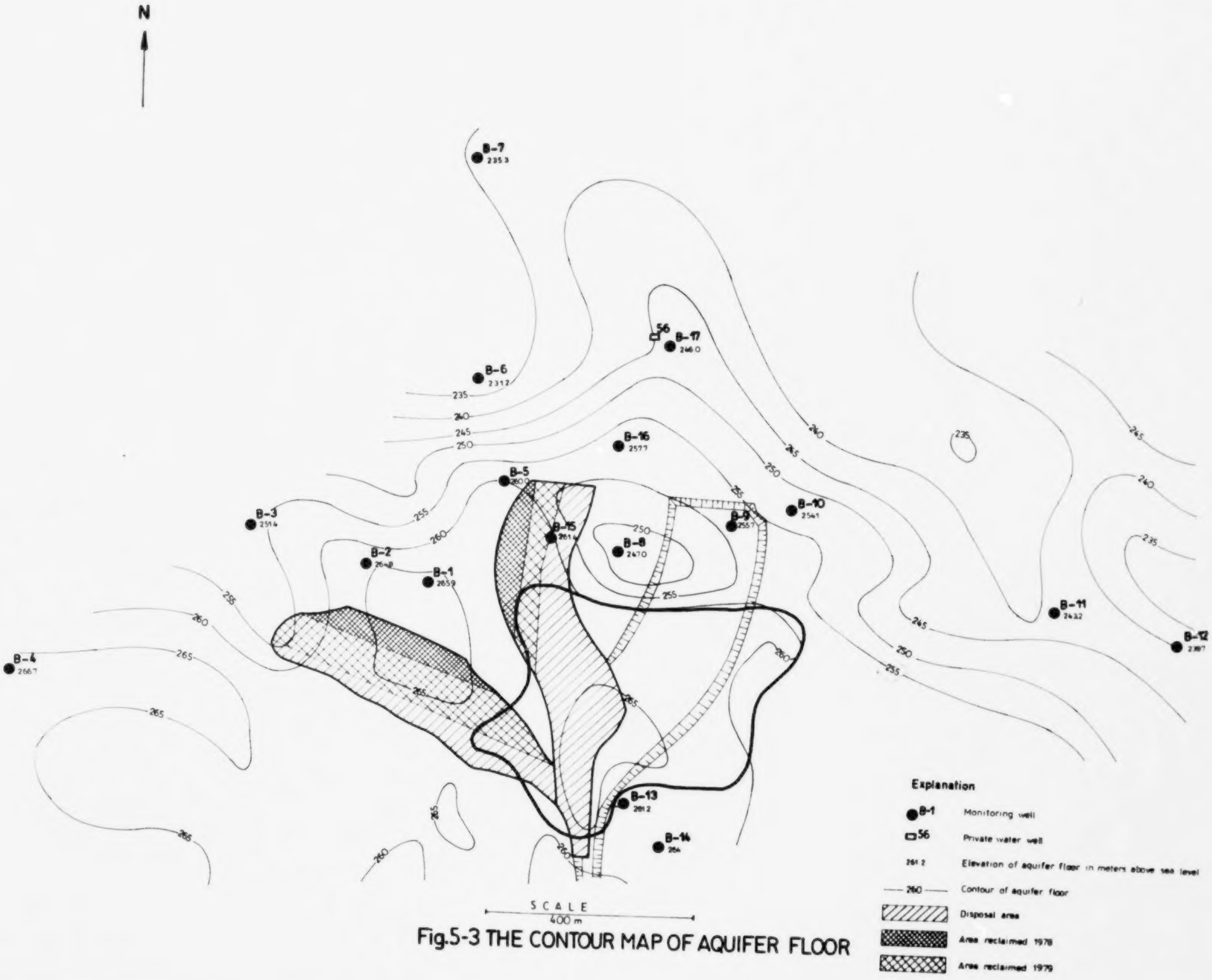

N
B-7
2353
B-6
2312
56
B-17
2460
B-16
2577
B-5
2600
B-3
2514
B-2
2648
B-1
2659
B-15
2614
B-8
2470
B-9
2557
B-10
2541
B-11
2432
B-12
2307
B-13
2612
B-14
264
B-4
2667
235
240
245
250
255
260
265
SCALE
400 m
Explanation
B-1 Monitoring well
56 Private water well
261 2 Elevation of aquifer floor in meters above sea level
260 Contour of aquifer floor
Disposal area
Area reclaimed 1978
Area reclaimed 1979

Fig.5-3 THE CONTOUR MAP OF AQUIFER FLOOR

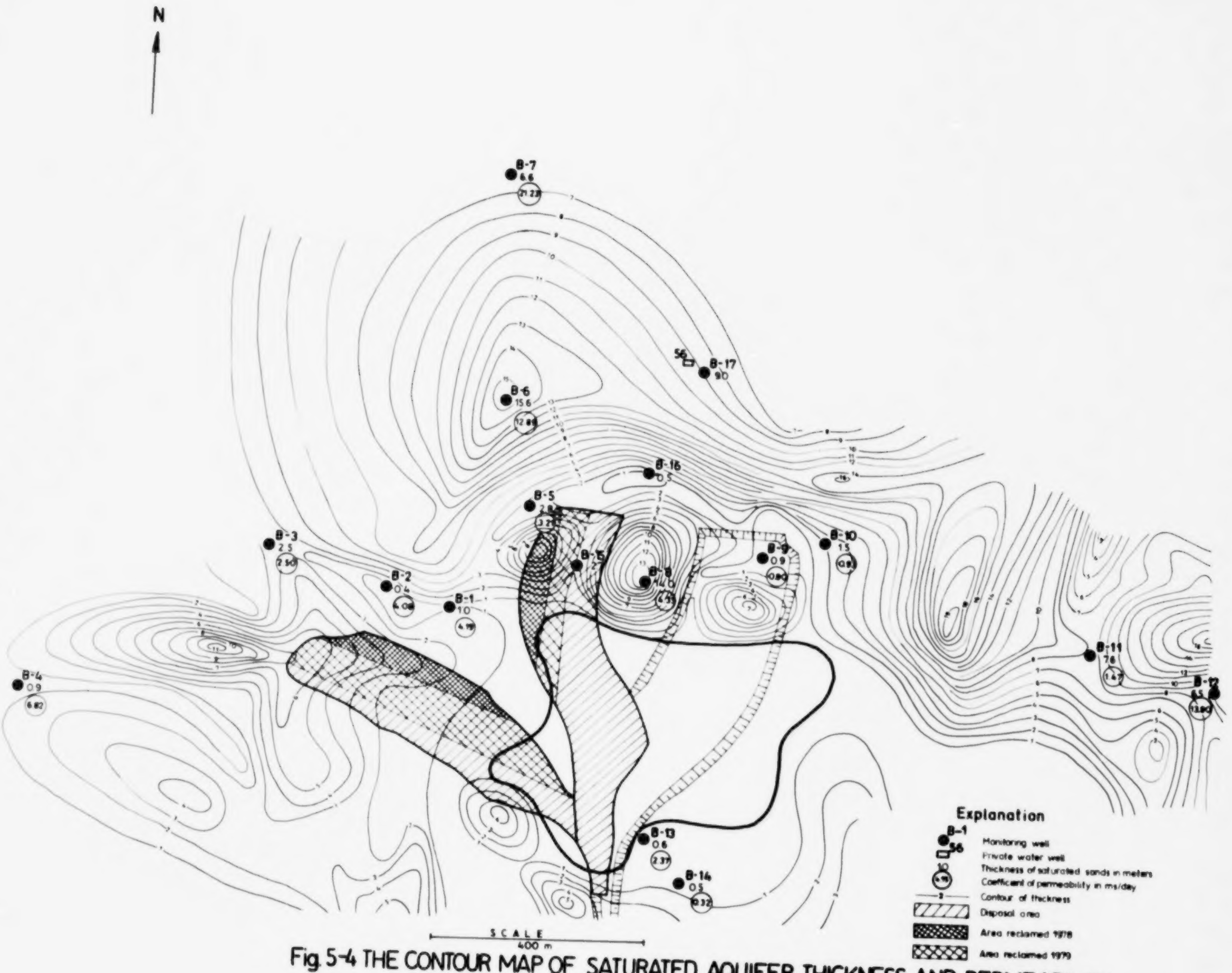

N
B-7
6.6
21.23
B-6
15.6
12.89
56
B-17
9.0
B-16
0.5
B-5
2.8
3.21
B-15
B-8
14.0
B-9
0.9
0.80
B-10
1.5
B-3
2.5
2.50
B-2
0.4
4.04
B-1
1.0
4.19
B-4
0.9
6.82
B-11
7.6
1.47
B-12
6.5
B-13
0.6
2.37
B-14
0.5
0.32
SCALE
400 m
Explanation
B-1
Monitoring well
56
Private water well
10
Thickness of saturated sands in meters
Coefficient of permeability in ms/day
2
Contour of thickness
Disposal area
Area reclaimed 1978
Area reclaimed 1979

Fig. 5-4 THE CONTOUR MAP OF SATURATED AQUIFER THICKNESS AND PERMEABILITY.

Quaternary Formation

The Quaternary formation lays on the impermeable tertiary subsoil and is formed from sand and clays 10 - 40 m thick (on the average 20-30 m). The clays prevail in the floor and the roof parts of the Quaternary formation and sand deposits form its center.

The thickness of the sand varies from 3 to 20 m, and in the bottom of the open pits where the sand was removed from 0 to 8 m. Within the sand, deposits of silt and gravel appear but they are narrow and are not wide spreading.

The permeability of the sand was determined using laboratory methods for all layers differing in lithological respect. For wells situated in close proximity to the waste, we determined the permeability of all layers from the surface down to the aquifer floor, and for other wells only layers occurring below the groundwater table. Values of the permeability coefficients for unsaturated layers near the disposal site were from 4 to 26 meters per 24 hrs. with respective values of specific yield between 0.12 and 0.18. The coefficient of permeability for the saturated part of the aquifer tested was extremely variable with limits of 1 to 33 meters per 24 hrs, although the majority of the layers had permeability coefficients from 3 to 10 meters per 24 hrs. The corresponding values of specific yield are within the range of 0.11 to 0.15. The thickness of the aquifer is between 1 and 12 m.

The groundwater table occurs at depths from 6.5 to 15 m below the ground surface. In the bottom of the open pits where the sand was removed, the depth is from 0.2 to 2 m. The absolute values of the position of the water-table within the disposal site fluctuated within a range of 262 to 266 m above sea level, and around the disposal within a range of 250 - 268 m above sea level.
The groundwater table is shown in Fig. 5-5.

Observations of the water table position performed approximately every 3 weeks indicated that changes in particular wells did not exceed 50 cm. A clear increase in the water table occurred in 1978 (40 to 100 cm) as compared to 1974 and 1975 as a result of increased precipitation.

Velocities of the flow of groundwater in the region of the disposal site (computed on the basis of heads distribution and permeability parameters) vary between 0.15 to 3 meters per day.

Finally, one more parameter should be mentioned - the coefficient of infiltration. In an empty open pit without surface run-off and without continuous vegetation cover, this can fluctuate between 0.6 to 0.8 per 24 hours, and between 0.4 to 0.6 a year. When an open pit is filled with waste material flush with the surrounding terrain and no vegetation is introduced, these values range from 0.4 to 0.7 and 0.3 to 0.5, respectively.

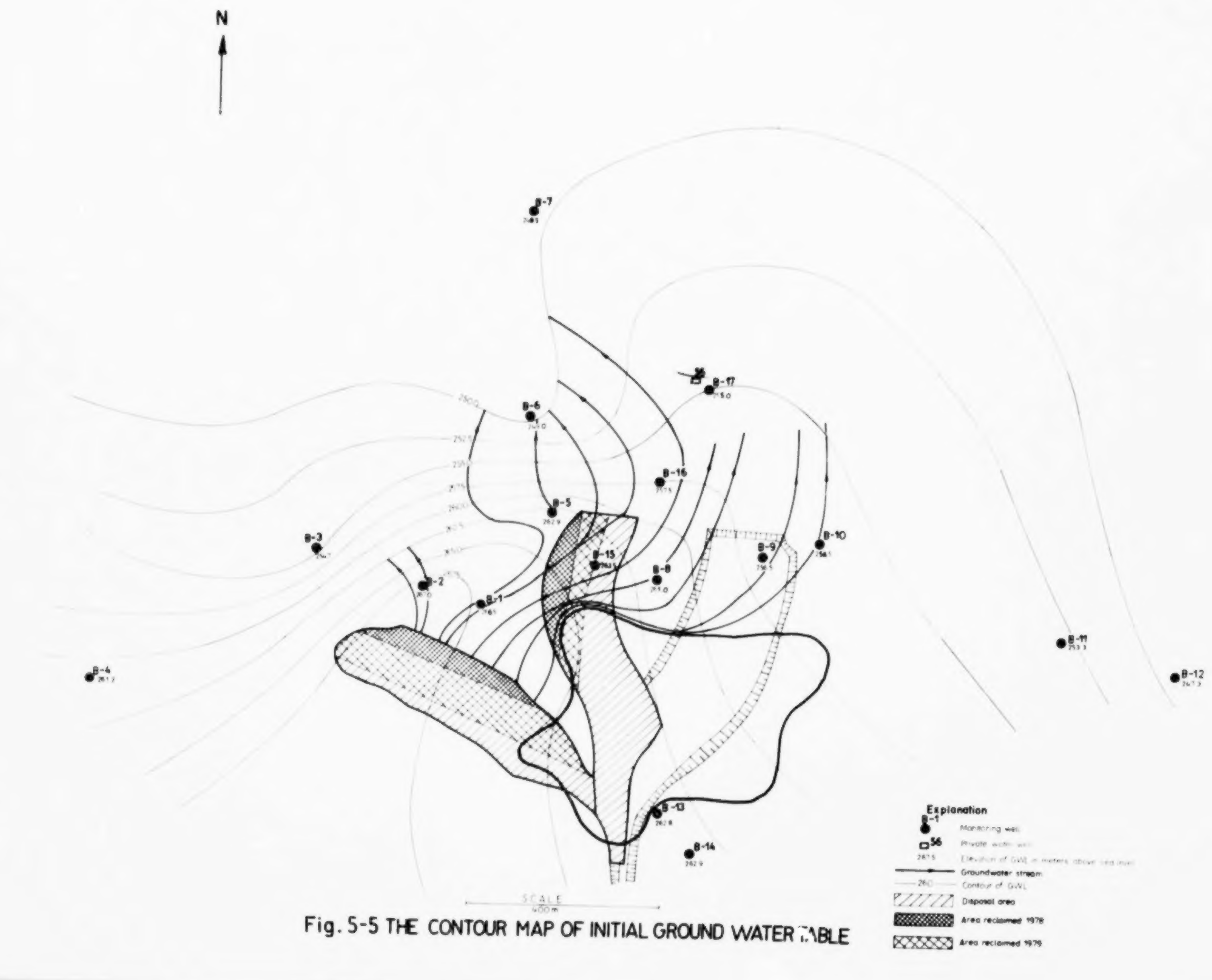

N
B-1
B-2
B-3
B-4
B-5
B-6
B-7
B-8
B-9
B-10
B-11
B-12
B-13
B-14
B-15
B-16
B-17
56
250.0
252.5
255.0
257.5
260.0
262.5
265.0
267.5
SCALE
400m
Explanation
B-1
Monitoring well
56
Private water well
247.5
Elevation of GWL in meters above sea level
Groundwater stream
260
Contour of GWL
Disposal area
Area reclaimed 1978
Area reclaimed 1979

Fig. 5-5 THE CONTOUR MAP OF INITIAL GROUND WATER TABLE

DETAILED DESCRIPTION OF THE DISPOSAL SITE

Considerable amounts of sand were removed from the disposal site during the 1950's and 1960's. The sand was used for backfilling in deep underground coal mines. The abandoned former sand pit was comprised of three separate pits connected to one another near their southern end. Two of these pits (Central and Western) were used for waste disposal.

Central Disposal Pit

The Central pit, where wastes were disposed first, was about 500 m long and 170 m wide, and had an average depth of 16.5 m. The pit bottom and slopes were sand, sometimes containing clay and silt. The thickness of the sand layer in the northern part of the disposal area has about 7.5 m, and in the southern part it increased to about 9 m, but in some places decreased to zero. The groundwater table was from 0 to 2 m below the pit bottom.

Western Disposal Pit

The western pit, planned as a reserve disposal area, was about 580 m long, about 150 m wide and had an average depth of about 7 m. Its bottom and sides were sand, sometimes containing clay and silt. The thickness of the sand layer in the pit bottom varied from about 1 m at its eastern end to about 6 m in its western end. The groundwater table was from 0.5 to 3 m below the pit bottom.

SECTION 6

CHARACTERISTICS OF THE DISPOSED WASTES

Continuous disposal of wastes from the adjacent bituminous coal mine began in January 1975. Approximately 30,000 to 45,000 m^3 of wastes were disposed monthly.

AMOUNTS OF DISPOSED WASTES

Table 6-1 presents the volume of waste disposed in quarterly periods, as well as the cumulative total. From a total of 2.09 mill. m^3 of waste material, about 1.51 mill. m^3 was disposed in the central disposal pit, and about 0.58 mill. m^3 in the western disposal pit. About 96 percent of the waste material consisted of coal refuse, and about 4 percent of powerplant ashes.

Table 6-2 presents the various surface areas of waste exposed to precipitation at each of the disposal sites. Between 1975 and 1977, the surface area of the waste exposed to precipitation and percolation gradually increased from 30,000 m^2 to 100,000 m^2. Reclamation of the disposal site began in 1978. This resulted in a decrease in the exposed surface area in 1979 to about 78,000 m^2 despite the fact that the volume of wastes increased. The surface area is an important factor which determines the amount of water, which by percolation, can contaminate groundwater.

The reclamation was executed in two phases. In the first phase, when the pit was filled to the original level of surrounding area (i.e., 272 to 281 m above sea level) the surface was very carefully compacted and covered with 0.3 m of clay. Then the decision to store more wastes on this disposal was made. That storage was done above the previous terrain to an artificial elevation three meters higher than the original surface - it now has elevations 275 m to 281 m above sea level. So in the second phase of reclamation the new operations were executed. The disposal was shaped so that the sides had a slope of 3:1, and the top flat area had an inclination of 4 percent. The surface was then very strongly compacted and because of an admixture of finely washed mud and fly ash, resulted in concrete character. Afterwards the shaped and compacted surface was covered by 0.5 to 0.6 m of clay topsoil. The final reclamation consisted of the introduction of trees and bushes on the slopes and grasses for pasture in the flat top area.

Table 6-1. Volume of Disposed Wastes

Years	Quarter	Central Disposal Pit				Western Disposal Pit				Total Cumulative Volume (m³)
		Disposed during quarter (m³)	Disposed to date (m³)	Percentage coal refuse	Percentage ashes	Disposed during quarter (m³)	Disposed to date (m³)	Percentage coal rafuse	Percentage ashes	
1975	I	14170	14170	96,2	3,8	-	-	95,7	4,3	14 170
	II	42300	56470			-	-			56 470
	III	93810	150280			68200	68200			218 480
	IV	89239	239519			40160	108360			347 879
1976	I	87250	326769	95,1	4,9	3480	111840	95,7	4,3	438 609
	II	47200	373969			63120	174960			548 929
	III	142941	516910			17360	192320			709 230
	IV	49729	566639			79340	271660			838 299
1977	I	112741	679380	96,7	3,3	4850	276510	96,7	3,3	955 890
	II	101320	780700			27810	304320			1085 020
	III	69420	850120			78430	382750			12328 870
	IV	103269	953389			16440	399190			1352 579
1978	I	120100	1073489	93,9	6,1	4770	403960	96,2	3,8	1477 449
	II	112745	1186234			7320	411280			1597 514
	III	91112	1277346			11120	422400			1699 746
	IV	11046	1288392			65459	487859			1776 251
1979	I	35250	1323642	95,2	4,8	39200	527059	95,2	4,8	1850 701
	II	69900	1393542			10440	537499			1931 041
	III	73450	1466992			6900	544399			2011 391
	IV	47718	1514710			35188	579587			2094 297
TOTAL		1514710	1514710	95,4	4,6	579587	579587	95,9	4,1	2094 297

Table 6-2. Surface Area of Waste Exposed to Precipitation

Years	Central Disposal Pit			Western Disposal Pit			Combined		
	Total m^2 (1)	Reclaimed m^2 (2)	Exposed m^2 (3)	Total m^2 (1)	Reclaimed m^2 (2)	Exposed m^2 (3)	Total m^2 (1)	Reclaimed m^2 (2)	Exposed m^2 (3)
1975	15, 256	-	15, 256	16, 173	-	16, 173	31, 429	-	31, 429
1976	34, 056	-	34, 056	34, 308	-	34, 308	68, 364	-	68, 364
1977	56, 156	-	56, 156	48, 478	-	48, 478	104, 634	-	104, 634
1978	76, 583	12, 700	63, 883	65, 208	16 000	49, 208	141, 791	28, 700	113, 091
1979	91, 571	35, 100	56, 471	83, 928	62 500	21, 428	175, 499	97, 600	77, 899

(1) Total surface in disposal area

(2) Surface area reclaimed by soil covering and vegetation

(3) Surface area of unreclaimed waste

THE QUALITATIVE CHARACTERISTICS OF DISPOSED WASTES

In order to determine the qualitative character of the waste material with respect to its leachability and pollution potential, samples of the disposed wastes were taken every 4 to 6 months. The samples came from recently disposed wastes and represented the material disposed at that time. About 10 kg of wastes was delivered to the laboratory for leaching tests.

The wastes were placed in glass columns, 100 cm high and with a diameter of 12 cm equipped with valves which regulated the rate of water flow through the waste. The waste was placed in the column on a layer of sand taken from the disposal floor. The ratio of waste thickness to the sand's thickness was about 4:1. The material was washed using a peristaltic pump with distilled water in a closed cycle.

Three successive leachings were performed until 5 dm^3 of water had been used. Each of them lasted 24 hours. The leaching rate of the first test was 1 dm^3/hr. and the others were 0.5 dm^3/hr. The amounts of 1.0 and 0.5 dm^3/hr. could be theoretically compared with 88 and 44 mm of rain per hour, respectively.

A total of 11 samples (two or three a year) were taken. Each was leached three times (as stated above) and the leachates were analyzed to determine pollution potential of the refuse. Detailed results of these analyses are presented in tables included in the Appendix. The data presented in these tables indicate that the content of the samples varied considerably, but the variations were within acceptable limits. Data from one sample taken in August 1979 differed so significantly from the rest that they were not used in calculating average values.

The refuse contained large amounts of coal sludge and therefore large amounts of colloid sediments were found in the leachate. The sediment at first caused gradual and then complete sealing of the underlaying sand layer in the glass column. This phenomenon hindered the leaching tests but may be very important at an actual disposal site. Dusts and colloids leached out of the refuse could seal up the disposal site bottom and prevent pollutants from leaching into the groundwater. This phenomenon which will occur under normal rain fall conditions will be much slower.

To evaluate the pollution potential every parameter leached will be discussed. The summary is shown in Table 6-3.

pH

pH of the leachates were generally alkaline. In most leaching tests it varied from 8.6 to 9.9. Only in 6 of the samples was it in the range of 7.3 to 7.9. In 8 samples the alkalinity of the leachates increased with succesive leachings. In the remaining samples this phenomenon was not observed.

Table 6-3. Summary of Leachability Tests

Designation	Unit	Maximum	Minimum	Average
pH		9.9	7.3	8.4
Conductivity	us/cm^2	2140	500	1500
TDS	mg/dm^3	3372	548	1600
Cl	"	479	51	209.2
SO_4	"	230	50	164.6
Na	"	357	44.5	243.7
K	"	48	4.1	26.3
Ca	"	355.9	5.2	75.9
Mg	"	21.85	0.42	7.3
Mn	"	2.995	0.035	0.729
Fe	"	75.8	0.11	24.65
NH_4	"	4.46	0.32	1.733
PO_4	"	3.140	0.036	0.522
CN	"	0.066	0.003	0.0252
Phenols	"	0.088	0.008	0.0282
Al	"	38.5	0.175	11.71
Zn	"	3.085	0.360	0.883
Cu	"	0.925	0.019	0.1974
Pb	"	0.271	0.034	0.1956
Cr	"	0.089	0.011	0.0364
As	"	0.133	0.008	0.0581
Sr	"	2.050	0.037	0.406
Hg	"	10.9	0.6	5.17
Cd	"	0.056	0.005	0.024
Mo	"	0.029	0.003	0.017
B	"	3.600	0.095	0.855

Conductivity

Conductivity of the leachates varied considerably in test samples, ranging from 500 to 2,140 us/cm (most frequently values were from 1500 to 2000 us/cm). Only one sample, taken in August 1979, showed very high conductivity (9,680 us/cm). It was found that conductivity of the leachates gradually decreased in each successive leaching. Conductivity in the second leachings were about 3 times lower than in the first, while in the third they were about twice as low as the second.

Total Dissolved Substances

The content of TDS in the leachates varied considerably from 550 to 3372 mg/dm^3, but in most cases it ranged from 1200 to 2000 mg/dm^3. In only one sample, taken in August 1979, the TDS content was high (4350 mg/dm^3). The average concentration of TDS in the leachates was 1600 mg/dm^3.

The concentration of dissolved substances in the leachates gradually decreased in successive leachings. The TDS in the first leachings ranged from 288 to 990 mg/dm^3, in the second leachings 154 to 852 mg/dm^3, and in the third, 106 to 325 mg/dm^3. In the first leachings 59 percent of the substances were leached, in the second, 25 percent and in the third, 16 percent. Since conductivity is an indirect indicator of TDS, the fact that the two follow the same trends is important.

Chlorine (Cl)

The content of Cl in the leachates varied from 50 to 260 mg/dm^3, and in one sample it was 479 mg/dm^3. The average concentration of Cl in the leachates was 209 mg/dm^3.

In all test samples the Cl content gradually decreased with successive leachings. Leachates from the first leachings varied from 30 to 180 mg/dm^3, from the second 10 to 87 mg/dm^3, and from the third, 5 to 36 mg/dm^3. The average percentage of Cl in the leachates were 66 percent in the first leachings, 21 percent in the second and 13 percent in the third.

Sulfate (SO_4)

The content of SO_4 in the leachates varied from 50 to 230 mg/dm^3 (except one sample which had a concentration of 2500 mg/dm^3); the average was 164.6 mg/dm^3. In the first leachings, 33 to 198 mg/dm^3 SO_4 was found in the leachates, in the second, 9 to 50 mg/dm^3 and in the third, 5 to 65 mg/dm^3. The percentages were 67 percent SO_4 in the first leaching, 19 percent in the second, and 14 percent in the third.

Sodium (Na)

The content of Na in the leachates varied from 44.5 to 357 mg/dm^3, however, most frequently (in 7 of the 11 samples) it ranged from 260 to 350 mg/dm^3. A gradual decrease in the Na concentration was observed in successive leachings. The Na content of the leachates from the first leachings varied between 23.5 and 290.0 mg/dm^3, from the second between 8.3 and 132.0 mg/dm^3, and from the third between 4.2 and 56.0 mg/dm^3. Average percentages of Na in the leachates were 66 percent in the first leachings, 20 percent in the second, and 14 percent in the third.

Potassium (K)

The content of K in the leachates varied from 4.1 to 48.0 mg/dm^3 (except in the sample from August 1979, it was 317 mg/dm^3). The average concentration of K (calculated from 10 samples) was 26.32 mg/dm^3.

A gradual decrease of K from consecutive leachings was observed in the leachates, except in two samples. The values from the first leachings, varied between 2.8 and 24.1 mg/dm^3 (59 percent). In the second leaching values ranged between 0.8 and 12.0 mg/dm^3 (22 percent). In the third leaching, the values varied between 0.5 and 14.0 mg/dm^3 (19 percent).

Calcium (Ca)

The content of Ca in the leachates varied from 5.2 to 30.8 mg/dm^3 except for two samples which showed values of 150 and 356 mg/dm^3 (August 1979). Ca levels in the leachates from the first leachings varied from 1.70 to 234 mg/dm^3, from the second 1.5 to 79.3 mg/dm^3, and from the third 1.9 to 55.0 mg/dm^3. Corresponding percentages of Ca leached in each test were 37 percent, 32 percent, and 31 percent.

Magnesium (Mg)

The content of Mg varied considerably (from 0.42 to 21.85 mg/dm^3), except for the sample from August 1979, which was 249.6 mg/dm^3. The average concentration of mg was 7.32 mg/dm^3. The products of Mg leachings were irregular. In successive leachings gradual increases as well as gradual decreases in the Mg concentrations were observed. In the first leachings, Mg content varied between 0.17 and 11.0 mg/dm^3, and in the third between 1.0 and 6.4 mg/dm^3. Average percentages of Mg in the leachates were 39 percent, 33 percent, and 28 percent, respectively.

Manganese (Mn)

The content of Mn in the leachates varied between 0.035 and 0.84 mg/dm^3. In one sample it was 2.995 mg/dm^3. Samples obtained after successive leachings showed gradual decreases as well as increases (in most cases) in Mn content. Except for one sample in the first leachings, the concentrations ranged from 0.023 to 0.305 mg/dm^3, in the second 0.005 to 0.555 mg/dm^3, and in the third 0.007 to 0.375 mg/dm^3. Percentages of Mn content was 41 percent, 34 percent, and 25 percent, respectively.

Total Iron (Fe)

The content of Fe in the leachates varied considerably between 0.11 mg/dm^3 and 75.8 mg/dm^3. In six samples Fe content ranged from 25 to 35 mg/dm^3. The average for all samples was 24 to 65 mg/dm^3. The content of Fe in successive leachings was irregular. The concentrations did not tend to increase or decrease in successive leachings. Fe content in the first leachates were from 0.045 to 48.600 mg/dm^3, in the second 0.050 to 25.000 mg/dm^3, and in the third 0.017 to 20.40 mg/dm^3. Percentages of Fe in the leachates were 38 percent, 41 percent, and 21 percent, respectively.

Ammonium (NH_4)

The content of NH_4 in the leachates varied considerably between 0.32 and 4.40 mg/dm^3. The average value was 1.73 mg/dm^3. The NH_4 leachings were irregular. In successive leachings both decreases and increases were noted. NH_4 concentrations in the first leachings varied from 0.10 to 1.87 mg/dm^3, in the second from 0.09 to 1.87 mg/dm^3, and in the third from 0.02 to 2.50 mg/dm^3. Percentages of NH_4 in the leachates were 44 percent, 28 percent, and 28 percent, respectively.

Phosphate ($P0_4$)

The content of $P0_4$ in the leachates varied from 0.036 to 3.140 mg/dm^3, its average being 0.522 mg/dm^3. The concentrations of leachates in certain samples differed from others. Some tests (about 50 percent) showed gradual increases of $P0_4$ content in successive leachings, while others showed gradual decreases in its concentrations. $P0_4$ content in the first leachates were 0.01 to 1.021 mg/dm^3, in the second 0.006 to 1.260 mg/dm^3, and in the third 0.008 to 0.800 mg/dm^3. Respective percentages were 31 percent, 28 percent, and 41 percent.

Cyanide (CN)

The content of CN in the leachates varied between 0.003 mg/dm^3 and 0.066 mg/dm^3; the average was 0.0252 mg/dm^3. In all tests gradual decreases in CN content was observed from successive leachings. CN concentrations in the first leachings varied from 0.001 to 0.031 mg/dm^3, in the second from 0.001 to 0.029 mg/dm^3, and in the third from 0.001 to 0.018 mg/dm^3. The percentages were 47 percent, 29 percent and 24 percent CN, respectively.

Phenols

The content of phenols in the leachates varied from 0.008 mg/dm^3 to 0.088 mg/dm^3; its average was 0.028 mg/dm^3. The concentration of phenols in the leachates from successive leachings varied considerably and either increased, decreased or showed no change. In the first leachings, the content varied from 0.001 to 0.064 mg/dm^3, in the second 0.003 to 0.010 mg/dm^3, and in the third 0.002 to 0.014 mg/dm^3. Respective percentages were 40 percent, 29 percent and 31 percent.

Aluminium (Al)

The content of Al in the leachates varied considerably from 0.175 to 38.5 mg/dm^3; its average was 11.71 mg/dm^3. The concentrations of Al in the leachates were very irregular in particular samples. In successive tests gradual increases as well as gradual decreases were observed. In the first leachings Al content varied between 0.05 and 16.00 mg/dm^3, in the second 0.05 and 18.00 mg/dm^3, and in the third 0.07 and 11.80 mg/dm^3. Percentages were 40 percent, 31 percent and 29 percent, respectively.

Zinc (Zn)

The content of Zn in the leachates varied between 0.360 and 3.085 mg/dm^3, however in 7 samples it did not exceed 0.635 mg/dm^3. The average Zn content was 0.883 mg/dm^3. In the majority of samples (8) gradual decreases of Zn content in the leachates from successive leachings were noted. In the first leachings Zn content ranged from 0.065 to 2.350 mg/dm^3, in the second 0.065 to 0.846 mg/dm^3, and in the third 0.035 to 0.650 mg/dm^3. Percentages were 48 percent, 34 percent and 18 percent Zn, respectively.

Copper (Cu)

The content of Cu in the leachates varied from 0.019 to 0.275 mg/dm^3 (one sample showed 0.925 mg/dm^3). The average was 0.197 mg/dm^3. In most test samples gradual decreases in Cu content were observed in successive leachings. Cu content in the first leachings were 0.007 to 0.730 mg/dm^3, in the second 0.003 to 0.115 mg/dm^3, and in the third 0.003 to 0.160 mg/dm^3. Percentages of Cu concentrations were 47 percent, 31 percent and 22 percent, respectively.

Lead (Pb)

The content of Pb in the leachates varied from 0.034 mg/dm^3 to 0.271 mg/dm^3, its average was 0.196 mg/dm^3. The Pb content in the leachates was irregular and either increased or decreased in successive tests.

Pb concentrations in the first leachings ranged from 0.015 to 0.147 mg/dm^3, in the second from 0.003 to 0.125 mg/dm^3, and in the third from 0.003 to 0.100 mg/dm^3. Respective percentages of Pb were 39 percent, 32 percent and 29 percent.

Chromium (Cr)

The content of Cr in the leachates ranged between 0.011 and 0.089 mg/dm^3 and its average was 0.0364 mg/dm^3. In successive leachings Cr content tended to increase, however, only small differences were found between second and third leachings. Cr concentrations in the first leachings were 0.002 to 0.032 mg/dm^3, in the second 0.002 to 0.24 mg/dm^3, and in the third 0.002 to 0.033 mg/dm^3. These concentrations were 43 percent, 30 percent and 27 percent of total Cr content, respectively.

Arsenic (As)

The content of As in the leachates varied from 0.008 to 0.133 mg/dm^3 and its average was 0.0581 mg/dm^3. Leaching of As in some samples was irregular and in successive tests decreased as well as increased. As concentrations in the first leachings ranged from 0.002 to 0.100 mg/dm^3, in the second leachings from 0.005 to 0.024 mg/dm^3, and in the third from 0.002 to 0.033 mg/dm^3. Percentages were 41 percent, 32 percent and 27 percent, respectively.

Strontium (Sr)

The content of Sr in the leachates varied from 0.037 to 0.749 mg/dm^3. In the sample taken in August 1979, it was 2.05 mg/dm^3. The average was 0.406 mg/dm^3. Leaching of Sr was irregular. In most cases (7 samples) Sr content decreased in successive leachings. In the first leachates, concentrations ranged from 0.017 to 1.600 mg/dm^3, in the second, from 0.010 to 0.480 mg/dm^3, in the third 0.005 to 0.190 mg/dm^3. The percentages were 51 percent, 27 percent and 22 percent of total Sr content, respectively.

Mercury (Hg)

The content of Hg in the leachates varied from 3.0 to 10.9 µg/dm^3. Only one sample (taken in March 1979), showed a value lower than 0.6 µg/dm^3. The average concentration of Hg was 5.17 µg/dm^3. In all samples, except two, Hg content in successive leachates gradually decreased. Hg concentrations in the first leachings varied from 0.8 to 5.0 µg/dm^3, in the second from 1.5 to 6.0 ug/dm^3 and in the third from 0.6 to 2.2 µg/dm^3. Percentages were 43 percent, 35 percent and 22 percent of total Hg content, respectively.

Cadmium (Cd)

The content of Cd in the leachates varied from 0.005 to 0.056 mg/dm^3 and its average was 0.024 mg/dm^3. In eight samples Cd concentrations gradually decreased in successive leachings. Higher Cd content was observed in the second leachings of 3 samples. Cd concentrations in the first leachings ranged from 0.002 to 0.017 mg/dm^3 (45 percent), in the second from 0.002 to 0.470 mg/dm^3 (6 percent), and in the third from 0.001 to 0.028 mg/dm^3 (19 percent).

Molybdenum (Mo)

The content of Mo in the leachates varied from 0.003 to 0.029 mg/dm^3 and its average value was 0.017 mg/dm^3. Mo content gradually decreased in the leachates from successive leachings. A gradual increase of Mo content was observed in two samples in the second leachings. Concentrations of Mo in the first leachings varied from 0.002 to 0.015 mg/dm^3, in the second from 0.001 to 0.010 mg/dm^3, and in the third from 0.000 to 0.006 mg/dm^3. Percentages were 48 percent, 36 percent and 16 percent of total Mo, respectively.

Boron (B)

The content of B in the leachates ranged from 0.095 to 3.600 mg/dm^3. The average value of B was 0.855 mg/dm^3. In successive leachings the B concentrations gradually decreased. In the first leachings it was from 0.043 to 1.670 mg/dm^3, in the second from 0.030 to 1.320 mg/dm^3, and in the third from 0.020 to 0.610 mg/dm^3. Respective percentages were 47 percent, 33 percent and 20 percent of total B.

SUMMARY

It may be concluded that the refuse contained large amounts of substances that were easy to leach.

The pattern of leaching of dissolved components, except for PO_4, Fe and phenols, was similar. Gradual decreases in their concentrations in successive leachings were observed. The largest amount of a component was usually leached in the first leaching, and the smallest during the last leaching period. Some of the pollutants were easier to leach, some more difficult (see Table 6-4).

In that respect, 3 groups of components (with similar leachability) can be distinguished.

Group I - Cl, SO_4, Na, K - 60 to 67 percent of their content was present in the leachate after the first 24 hour period, 19 to 22 percent after the second period, and 13 to 19 percent after the third period - the most leachable group.

Group II - Cu, Zn, Hg, Sr, Cd, B, Mn, Mo, CN - 41 to 51 percent of their content was measured in the leachate after the first leachings, 27 to 36 percent after the second, and 19 to 25 percent after the third - the average leachable group,

Group III - Mg, Al, Cr, As Pb, NH_4, Ca - 39 to 43 percent of their content carried into the leachate after the first leachings, 30 to 33 percent after the second, and 27 to 30 percent after the third - the less leachable group.

Table 6-4. Percentage of Component Leached in Each 24 Hour Leaching Test

Group	Designation	Average from all tests		
		First leaching	Second leaching	Third leaching
I	TDS	59	25	16
	Cl	66	21	13
	SO_4	67	19	14
	Na	66	20	14
	K	59	22	19
II	CN	47	29	24
	Mn	41	34	25
	Ca	37	32	31
	Cu	47	31	22
	Zn	48	33	19
	Hg	43	35	22
	Sr	51	27	22
	Cd	45	35	20
	Mo	48	36	16
	B	47	33	20
III	Mg	39	33	28
	Al	40	31	29
	Cr	43	30	27
	As	41	32	27
	Pb	39	32	29
	NH_4	44	28	28
IV	PO_4	31	28	41
	Phenols	40	29	31
	Fe total	38	41	21

The leaching process for phosphates, phenols and iron differed from the above groups and therefore were not mentioned in any of the groups.

Phosphates in the first and in the second leachings showed similar concentrations but were 25 percent lower in concentrations in the third leachings,

Total iron - 41 percent was leached during second leachings,
Phenols - most frequently leached in the first and in the third leachings.

The above figures provide information on the leachability of particular components in time. The data also assists in the interpretation of the pollution potential. It can provide insight as to whether the amount of a pollutant in groundwater is caused by its concentration in the wastes or by its leachability. In the case where the occurrence of leachability is slow the hazard may be delayed, but still exists.

THE QUANTITATIVE CHARACTERISTICS OF POLLUTANTS' CONTENT

In order to estimate the quantitative potential of the leachable pollutants in the coal waste mass, the necessary calculations were made. The results are shown in Table 6-5.

Figures illustrate the amount of leachable pollutants in milligrams (mg) per one kilogram (kg) of coal waste after 3 x 24 hours = 72 hours leaching.

The received values could differ from the real because of only 72 hours leaching and because of full saturation and constant water flow in glass columns. However, they give the ranges and help to estimate the range of hazard.

Table 6-5. Average Concentration of Particular Components and the Amount of Each Component Leached from Kilogram of Coal Refuse in Laboratory Leachings

Designation	1975		1976		1977		1978		1979		1975 - 1979	
	concentration	amount	concentration	amount	concentration	amount	concentration	amount	concentration	amount	concentration	amount
	mg/dm^3	mg/kg	mg/dm^3	mg/kg	mg/dm^3	mg/kg	mg/dm^3	mg/kg	mg/dm^3	mg/kg	mg/dm^3	mg/kg
TDS	1283.0	256.6	2991	598.2	1254.6	250.92	1111.0	222.2	1362.0	272.4	1600.0	320.0
Cl	479.0	95.8	127.0	25.4	167.6	33.52	146.0	29.2	126.5	25.3	209.2	41.84
SO_4	166.8	33.36	165.3	33.06	135.3	27.06	25.12	25.12	230.0	46.0	164.6	32.92
Na	347.0	69.4	207.2	41.44	159.0	31.8	202.8	40.56	302.9	60.58	243.7	48.74
K	48.0	9.6	18.4	3.68	15.2	3.04	16.1	3.22	33.9	6.78	26.32	5.26
Ca	150.0	30.0	12.7	2.54	8.5	1.7	23.1	4.62	185.3	37.06	75.9	15.18
Mg	5.5	1.1	12.6	2.52	4.79	0.96	10.7	2.14	3.0	0.6	7.30	1.46
Mn	0.950	0.19	0.511	0.102	0.541	0.108	0.128	0.026	1.515	0.303	0.729	0.146
Fe	23.86	4.77	20.04	4.01	20.1	4.02	21.28	4.26	37.98	7.60	24.65	4.93
NH_4	2.40	0.48	0.92	0.184	2.226	0.445	1.760	0.352	1.340	0.268	1.733	0.347
PO_4	0.152	0.03	0.081	0.016	0.983	0.197	0.651	0.13	0.741	0.148	0.522	0.104
CN	-	-	0.0087	0.0017	0.0376	0.0075	0.019	0.0038	0.0356	0.0071	0.0252	0.005
Phenols	0.060	0.012	0.021	0.0042	0.037	0.0074	0.011	0.0022	0.012	0.0024	0.0282	0.0056
Al	0.178	0.036	13.8	2.76	12.43	2.49	19.1	3.82	13.05	2.61	11.71	2.34
Zn	0.404	0.081	0.443	0.089	0.743	0.149	1.053	0.211	1.772	0.354	0.883	0.177
Cu	0.052	0.010	0.212	0.012	0.126	0.025	0.128	0.026	0.472	0.094	0.1974	0.0395
Pb	0.019	0.0038	0.163	0.0326	0.185	0.037	0.106	0.0212	0.505	0.101	0.1956	0.0391
Cr	0.041	0.0082	0.024	0.0048	0.037	0.0074	0.050	0.01	0.030	0.006	0.0364	0.0073
As	0.012	0.0024	0.068	0.0136	0.123	0.0246	0.085	0.017	0.0025	0.0005	0.0551	0.0116
Sr	0.245	0.049	0.135	0.027	0.228	0.046	0.279	0.056	1.145	0.229	0.406	0.081
Hg	1.5	0.3	7.0	1.4	7.2	1.44	6.9	1.38	3.25	0.65	5.17	1.03
Cd	0.056	0.011	0.022	0.004	0.009	0.002	0.009	0.002	0.023	0.005	0.024	0.005
Mo	0.021	0.004	0.013	0.003	0.020	0.004	0.016	0.003	0.016	0.003	0.017	0.003
B	0.456	0.091	0.122	0.024	0.695	0.139	1.803	0.361	1.197	0.239	0.855	0.171

SECTION 7

GROUNDWATER MONITORING AND SAMPLING

MONITORING WELLS

In March 1974, 14 monitoring wells, number 1 to 14, were installed to monitor the aquifer surrounding the disposal area. The wells were bored in 4 sections radiating from the Central Disposal Pit toward the North, East, South and West.

- Wells 5, 6 and 7 were located toward the North; their distances from the disposal site were 50 m, 250 m and 700 m, respectively,
- Wells 8, 9, 10, 11 and 12 were located to the East; their distances from the disposal site were 100 m, 300 m, 400 m, 900 m and 1200 m, respectively,
- Wells 13 and 14 were located in the South; their distances from the disposal site were 150 m and 250 m, respectively.
- Wells 1, 2, 3 and 4 were located in the West (parallel to the Western Disposal Pit); their distances from the Central Disposal Pit were 100 m, 250 m, 500 m and 1000 m, respectively.

All monitoring wells were drilled by the dry system method down to the roof of the continuous tertiary layer. The depths of the wells varied from 7 to 27 m. The lithology of all layers found in each well was described in detail and samples were taken for laboratory analysis to determine permeability and specific yield.

Each well was lined with a filtration column of 6" diameter. The lining consisted of:

- a solid steel pipe in the lowest section which formed a settling tank,
- a filter, consisting of a perforated pipe wrapped with copper gauze and covered with gravel packing,
- a solid pipe terminating about 1 m above the ground surface and covered by a special protecting arrangement.

The space between well wall and filtration column was sealed in order to prevent direct infiltration from surface (rain) water into the well.

In 1977 three additional monitoring wells were drilled in the area north east of the disposal site because a model analysis of the hydrodynamic network suggested that the groundwater flow might run in that direction. These wells were located as follows: well no. 15 in the northern part of the Central Disposal Pit, wells no. 16 and 17 at a distance of 200 and 400 m, respectively from the edge of disposal site. The well depths and construction design were similar to the other wells. In 1978 two hand-excavated private farm wells (presently unused) numbered 56 and 67 were included in the monitoring system. They lay northeast of the disposal area, 330 and 60 m respectively from the Central Disposal Pit.

The location of wells and diagram of well installation is shown in Figure 7-1.

MEASUREMENTS AND SAMPLING

Water samples for physico-chemical analyses were taken from the monitoring wells from 1974 until the end of 1979. Prior to the water sampling, the groundwater table in each well measured within ± 2 cm. Then a volume of water equal to that in the wells was removed. After the well had again filled with fresh groundwater, it was sampled. This procedure was applied to avoid sampling water which had been in the well for a long period of time, coming in contact with the air and the pipe. The small volume of water removed from each well was found as the most proper to prevent the disruption of the natural hydrodynamic system which may happen if a large volume were removed.

The above operations were performed on a regular 3 week interval. Until October 1976, every fourth sample was taken for full analysis (42 parameters), while all others were taken for simple analysis (14 parameters). After October 1976, every third sample was taken for full analysis. A total of 85 sets of water samples were taken for physico-chemical analysis between 1975 and 1979, of which 26 sets had full analysis.

The above general scheme was slightly modified during the 5 year investigation. The modifications were as follows:

- Since November 1975, observations and sampling in well no. 4 located about 1000 m from the disposal site was discontinued because the groundwater table was higher in this well as compared with the disposal area. In addition, it was found that the water was polluted by other sources.

- Since April 1977 and July 1977 measurements and sampling in wells 12 and 11 were respectively eliminated because of the great distance from the disposal area and no significant slope of the groundwater table was observed in that direction. The introduction to the monitoring system of more useful new wells numbered 15, 16 and 17 made 11 and 12 unnecessary.

- The farm well no. 67 was eliminated after one sampling because of organic pollution by farm waste.

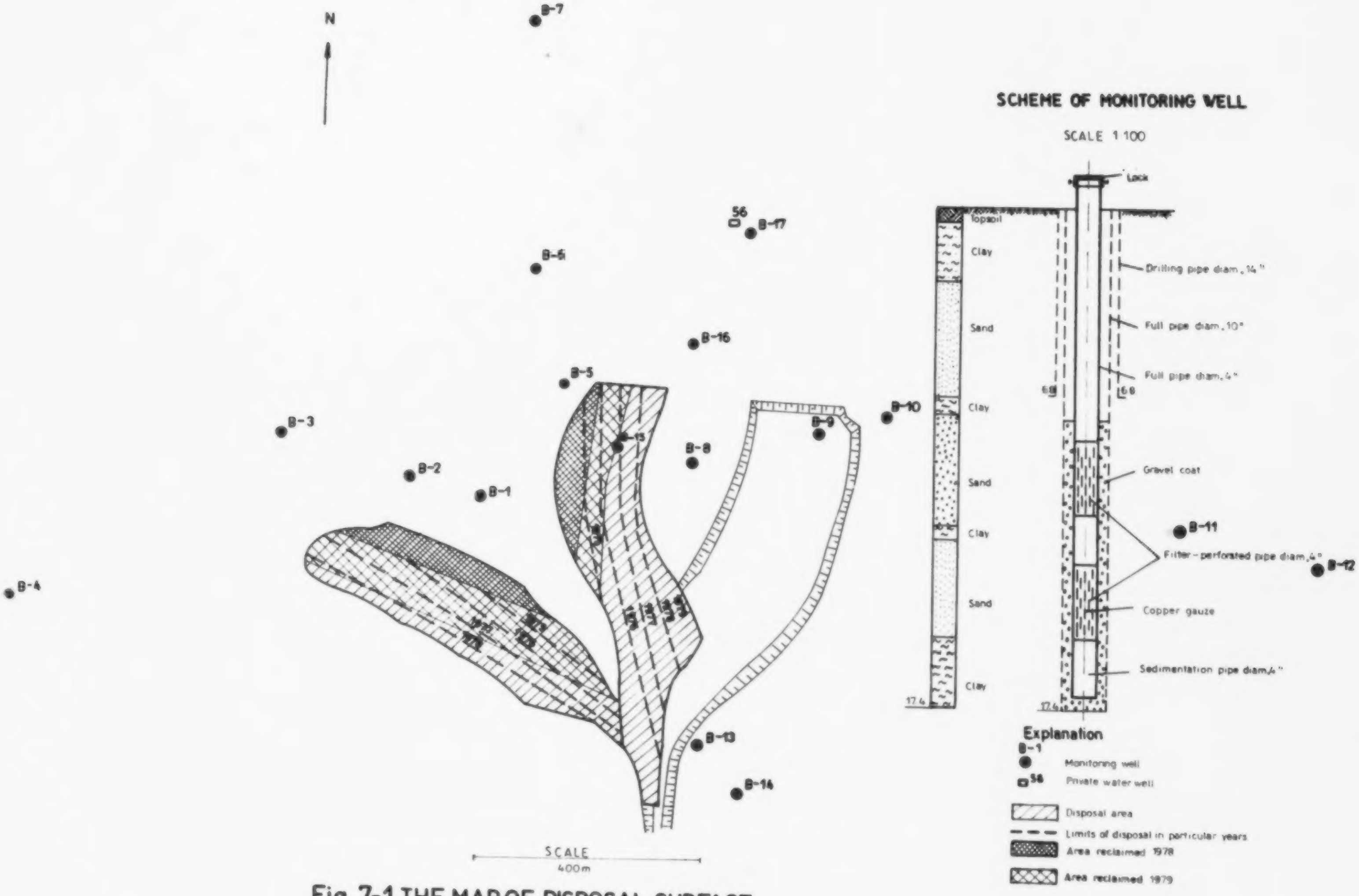

N
B-7
B-6
B-3
B-2
B-1
B-4
B-5
B-15
B-16
56
B-17
B-8
B-9
B-10
B-13
B-14
SCALE
400m
SCHEME OF MONITORING WELL
SCALE 1 100
Lock
Topsoil
Clay
Sand
Clay
Sand
Clay
Sand
Clay
17.4
6.8
6.8
17.4
Drilling pipe diam. 14"
Full pipe diam. 10"
Full pipe diam. 4"
Gravel coat
Filter-perforated pipe diam. 4"
Copper gauze
Sedimentation pipe diam. 4"
B-11
B-12
Explanation
B-1
Monitoring well
56
Private water well
Disposal area
Limits of disposal in particular years
Area reclaimed 1978
Area reclaimed 1979

Fig. 7-1. THE MAP OF DISPOSAL SURFACE

- Since April 1978, measurements and sampling were not performed in well no. 15 because it was destroyed.

The modifications were made in agreement with the Project Officer. A few additional differences in the planned program of sampling became necessary.

- Samples from all wells were not taken in January 1979 because of heavy snow which prevented sample collection.
- Water samples were not taken during the following periods because of temporary damages to the wells:
    - July, August 1978 and in October, November 1979 from well no. 1
    - December 1978 and July 1979 from well no. 13
    - June 1979 from well no. 7.

The above exceptions were not more than 1 percent of the measurements and samplings, so they were not considered important to the results of the investigation.

It can be concluded that both the wells' locations and the system of measurements and sampling proved useful and enabled the assessment of the tested phenomena.

SECTION 8

METHODOLOGY OF CHEMICAL ANALYSIS

For the routine analyses the water was collected in 5 dm^3 polyethylene containers from each well. For the full analyses, water samples were taken in the following quantities:

- 5 dm^3 in polyethylene containers;
- 1 dm^3 in glass containers for the determination of phenols (these samples were stabilized immediately with phosphoric acid and copper sulphate);
- 1 dm^3 in polyethylene containers to determine cyanides (the samples were immediately stabilized with the addition of potassium hydroxide KOH granules).

Samples were delivered to the laboratory within 3 to 5 hours. After delivery to the laboratory the samples were subjected immediately to vigorous stirring in a mixer, then filtrated, divided and acidified. Immediate acidification in the field was abandoned because of the following reasons:

- the delivery of samples to the laboratory took only a few hours;
- it was more appropriate to perform analyses on a large average sample rather than on small, separate samples;
- from the point of view of this investigation, the dissolved substances were more important than the suspended matter. In the course of filtration through a porous medium, the suspended matter sedimented on the grains of the soil (the methodology of research would have been somewhat different if the flow of polluted water passed through a fissured medium). The above procedures are recommended by the Polish Standards for sampling wells used for drinking water.

The filtered samples were analyzed employing the following analytic methods:

- color - utilizing a dichromate - cobaltic pattern scale
- smell - organoleptically, cold, according to a 5 - grade scale of smell intensity, and the following symbols for type of smell: R - vegetative smells, G - for putrescible, and S - for specific smells

- conductivity - by means of a conductometer
- pH - by potentiometric method
- total hardness - through titration with the EDTA reagent
- basicity - through titration with hydrochloric acid against methyl orange
- acidity - by titration with sodium hydroxide against phenolphthalein
- instant oxygen consumption - through titration, cold, with permanganate of potash
- oxygen consumption - through determination of the potash permanganate consumption by a sample during heating in a water bath for 20 minutes
- total dissolved substances - through the determination of residue after evaporation of a filtrated sample, and drying it at 105°C to a constant weight
- dissolved mineral substances - determined through roasting the dry residue from the filtrated sample at 600°C
- dissolved volatile substances - calculated from the difference between the total dissolved substances and the mineral substances
- chlorides - by Volhard method of titration with silver nitrite
- sulphates - with the nephelometric method by means of an autoanalyzer
- nitrates - by the colorimetric method and the use of an autoanalyzer after reducing to nitrites with an hydroxylamine solution
- ammonia nitrogen - distillation method with the Nessler reagent
- albumin nitrogen - distillation method with the Nessler reagent, after alkaline decomposition in a potash permanganate solution
- phosphates - colorimetric method in reaction with ammonium molybdate and a reduction to molybdate blue
- free cyanides - extraction colorimetric method after distilling sample acidified with tartaric acid, brominating and reacting with a bentidine - phyridine reagent
- phenols - monohydric phenols were determined after distilling the sample, with colorimetric method in aminoantipyrine
- bivalent iron - colorimetric method in reaction with 1.10 phenanthroline

- total iron - colorimetric method with 1.10 phenanthroline after reduction of trivalent iron
- trivalent iron - calculated from difference of the above two determinations
- calcium, sodium, potassium - by flame photometry method
- copper, zinc, lead, magnesium, manganese, strontium, cadmium - by atomic absorption
- aluminium - colorimetric method with aluminon
- chromium - colorimetric method with diphenylcarbazide
- arsenic - molybdate colorimetric method after reducing arsenous hydride from sample and oxidizing with sodium hypodromite to As^{5+},
- mercury - after reducing to elemental mercury and determined by colorimetric method in reaction with iodine and copper salts
- silica - dissolved reactive silica was determined with ammonium molybdate
- $B.O.D._5$ - biochemical oxygen demand was determined in analyses of samples for oxygen content using the Winkler method before and after the 5-day incubation period at 20°C
- molybdenum - colorimetric thiocyanate method
- boron - colorimetric method in reaction with bianthrimide in an environment of concentrated sulphuric acid.

SECTION 9

RESULTS AND DISCUSSION OF HYDROCHEMICAL TESTS

A complete set of results of the groundwater analysis is available in EPA Region III and Poltegor. In this section the results are presented in diagrams and discussion. On the diagrams the content of each component in every well is presented in columns which reflect quarterly averages. Quarterly average values were used instead of results from every sample because it is more informative and easier to read. The diagrams are grouped according to their location. Wells 1-3, 5-7, 8-10, 13 and 14, and 15-17 delineate sections. The first well in each group is always the one closest to the disposal site. Looking at the diagrams horizontally it is easy to see how the concentration of each pollutant changed with the time. By looking at the diagrams vertically, one may compare the differences between wells and sections during the same time period. Each pollutant is discussed with respect to the changes which occurred in each group of monitoring wells.

pH Reaction

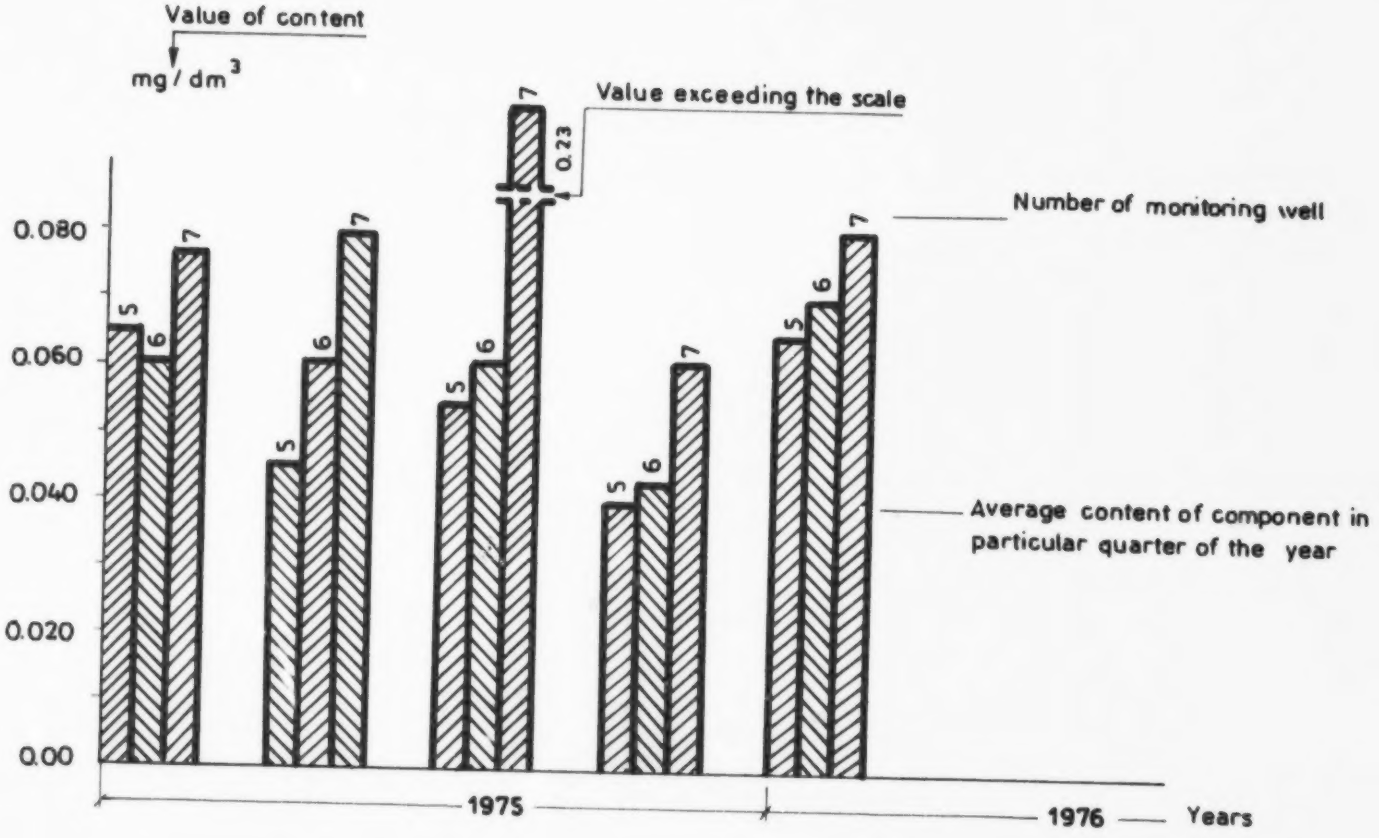
The pH of laboratory leachates varied from 7.3 to 9.9 averaging 8.4, i.e., the leachate was alkaline. Before disposal operations, pH of the groundwater ranged from 6.2 (in monitoring wells B-3, B-5) to 7.3 (in well B-14).

During disposal operations (1975-1979) the pH did not change significantly, and similar to the predisposal period, did not show any differences regardless of the time or location of observations. In all monitoring wells, except B-6, B-7 and B-17, the values varied approximately from 5.8 to 7.4. During the period July through October 1976, the pH in Well B-6 ranged from 8.4 to 8.7. In Well B-7, the pH value varied from 7.5 to 8.0 between November 1977 and August 1978. Between June 1978 and February 1979, the pH in well B-17 varied from 7.8 to 8.5.

An influence of waste disposal on pH of the groundwater was not observed. However, the acidity of waters in the investigated area tended to increase slightly, but was probably not due to the impact of disposal.

It is possible that the pH reaction of rains could change in the investigated region, but this has not been examined.

Explanation of diagrams



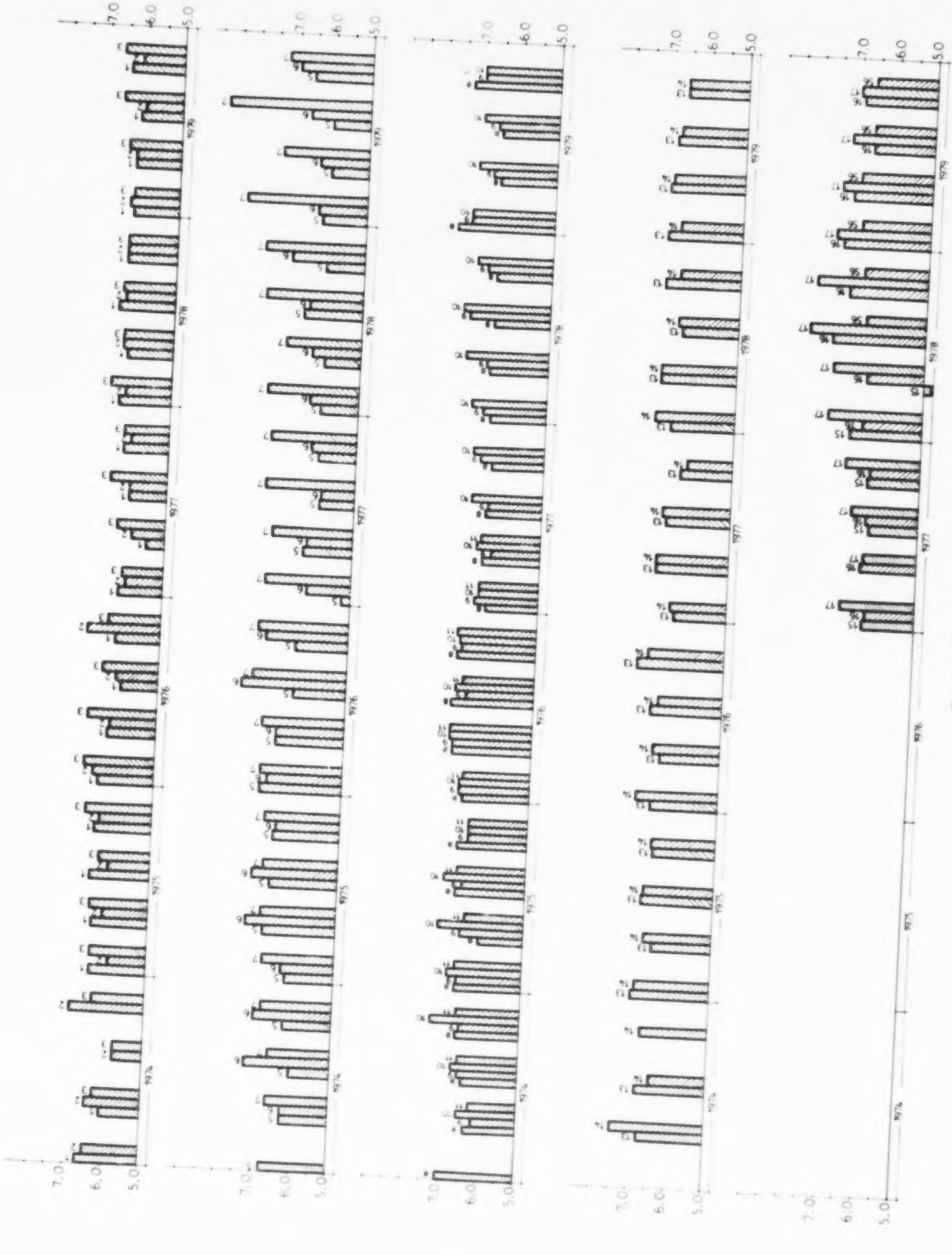


Fig.9-1.The diagram of pH reaction

Conductivity

Laboratory leachate conductivity ranged from 500 to 2140 µS/cm, the average value being 1500 µS/cm. Conductivity of groundwater before disposal (1974) varied from 174 µS/cm (well B-5) to 350 µS/cm (well B-7).

During the first two years of disposal operations (1975-76) groundwater conductivity remained on the level observed in 1974, i.e., approximately between 200 and 300 µS/cm. Beginning in 1977, conductivity began to change. Increased values were first observed in well B-6 in January 1977, while at the same time the values in the remaining wells did not exceed 250 µS/cm. From January 1977 until September 1978 conductivity of water in well B-6 increased considerably, ranging from 450 to 500 µS/cm. Further increases in conductivity were later observed and maximum values of 800 to 850 µS/cm were attained in May and June 1979. In June 1979, the values dropped to 500 to 550 µS/cm and remained there until project completion at the end of 1979.

An increase in water conductivity (360 uS/cm) was observed in well B-2 beginning in June 1977. Between June 1977 and July 1978, the average value ranged here from 400 to 500 µS/cm, and during August 1978 reached 580 µS/cm. From then until February and March 1979, the conductivity gradually increased to a maximum of 1050 to 1170 µS/cm. After that period conductivity dropped to between 600 and 800 µS/cm in August 1979 and 370 to 450 µS/cm at the end of 1979.

A continuous increase of conductivity was also observed in well B-1 beginning in September 1977 and in most cases maintained at a level of 450 to 500 µS/cm until June 1978. Between October and December 1978, conductivity increased considerably to 1100 µS/cm. Maximum values of 1100 to 1350 µS/cm were observed from January to April 1979. By August 1979, water conductivity had dropped to about 700 to 800 µS/cm and then further decreased to 450 µS/cm by the end of 1979.

A continuous increase in water conductivity was observed in well B-3. From December 1977 until September 1978, it varied from 400 to 500 µS/cm and then gradually reached a maximum of 1300 µS/cm in February and March 1979. Conductivity dropped to between 450 and 550 µS/cm and remained there through the end of the observations.

Water conductivity increase in well B-5 were less clear. From July 1978 until April 1979, it increased and fluctuated between about 400 and about 600 µS/cm. Then conductivity decreased slightly and remained at a level of 300 to 450 µS/cm until the end of the observation period.

Between 1977 and 1979, water conductivity in the other wells varied between 200 and 300 µS/cm.

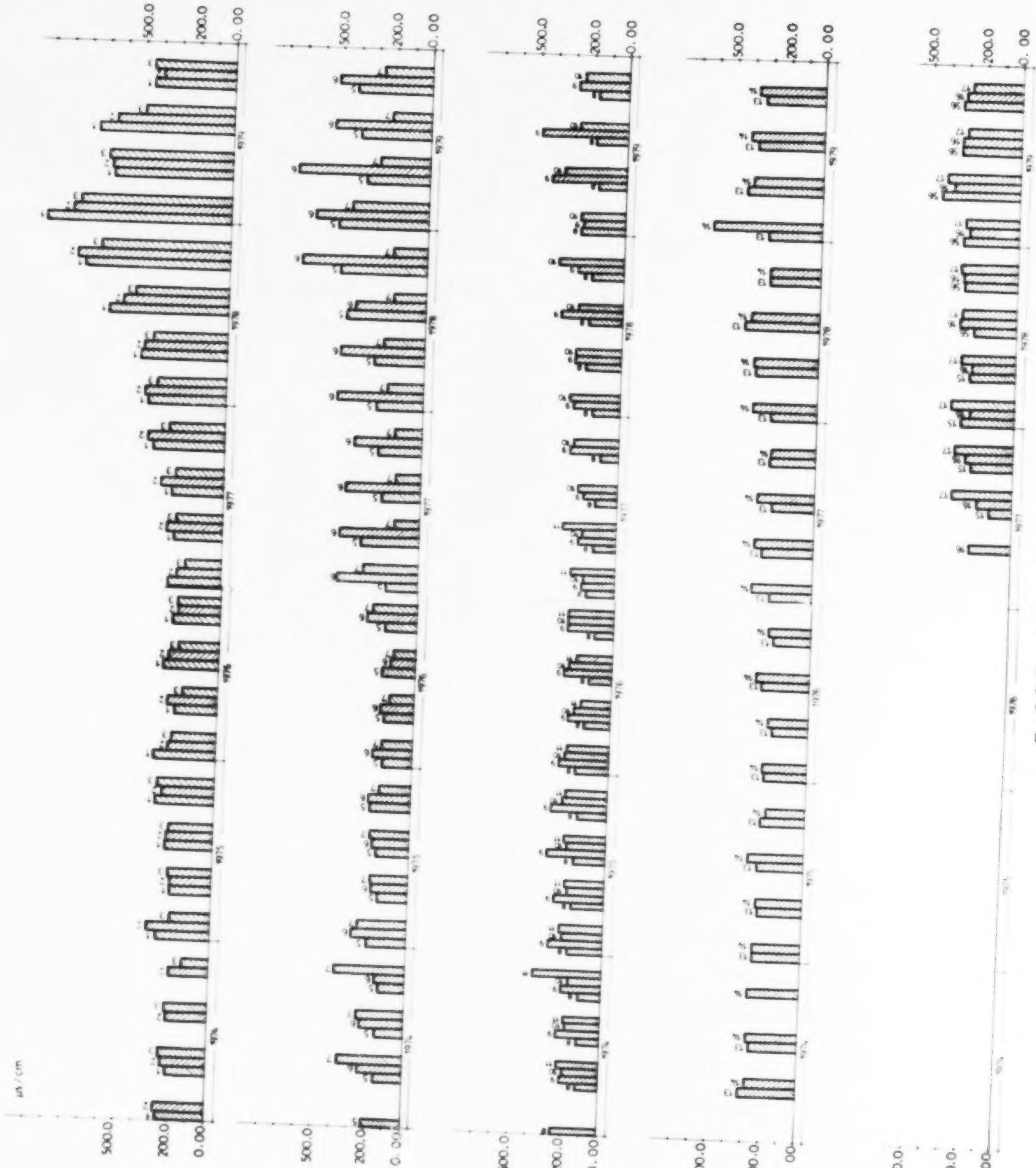


Fig. 9-2. The diagram of conductivity

It may be concluded that the disposal of coal wastes began to affect groundwater conductivity beginning in 1977, two years after waste disposal began. The phenomenon intensified until the first quarter of 1979 when maximum values were noted. Coal waste disposal affected the adjacent aquifer 200 to 300 m northward, i.e., in the direction of groundwater flow. The remaining sections of the aquifer showed no effects from the disposal.

Total Dissolved Substances

The content of TDS in laboratory leachates varied from 500 to 3372 mg/dm^3, averaging 1600 mg/dm^3.

Before coal waste disposal (1974), the content of TDS in groundwater ranged from 100 mg/dm^3 (wells B-5, B-8) to 350 mg/dm^3 (wells B-7 and B-13). Until the end of 1976, the TDS content did not change and in most cases remained between 100 and 200 mg/dm^3. Values of 350 to 450 mg/dm^3 (wells B-9, B-10, B-14) were only occasionally observed.

The situation began to change in the beginning of 1977 when significantly increased TDS content (360 mg/dm^3) was observed in well B-6 in January 1977 (at the same time TDS in the other wells varied from 120 to 270 mg/dm^3). The TDS content in well B-6 remained between 350-450 mg/dm^3 until April 1979 and reached its maximum of 700 mg/dm^3 in May and June 1979. Then it dropped to about 350 mg/dm^3. After June 1979, the TDS content ranged from about 230 to 350 mg/dm^3, the average being 303 mg/dm^3.

In well B-1, the increase of TDS content was observed in April 1978 when it reached 306 mg/dm^3. It gradually increased and reached 840-880 mg/dm^3 between January and March 1979. Then TDS dropped here to 420 to 550 mg/dm^3 until September 1979, and then to 300 mg/dm^3 by December 1979.

In well B-2, the increase in TDS followed the pattern in B-1. From April 1978 until March 1979, a gradual increase of TDS (from about 300 mg/dm^3 to 750 mg/dm^3) was noted. In April 1979, it decreased to 350-550 mg/dm^3 and remained unchanged until September 1979. Further decreases in TDS contents to about 270-320 mg/dm^3, averaging 297 mg/dm^3, was observed until the end of the investigation.

From April 1978 until March 1979, TDS content increased also in well B-3, ranging from 350 mg/dm^3 to 880 mg/dm^3. Then TDS content rapidly dropped to 220 to 350 mg/dm^3 and remained at this level until the end of 1979, except for a temporary increase to about 600 mg/dm^3 recorded at the end of May and beginning of June 1979.

Occasionally (in July 1978 and February 1979) high content of TDS (350-540 mg/dm^3) was also observed in well B-5, which is the closest to the disposal and downstream.

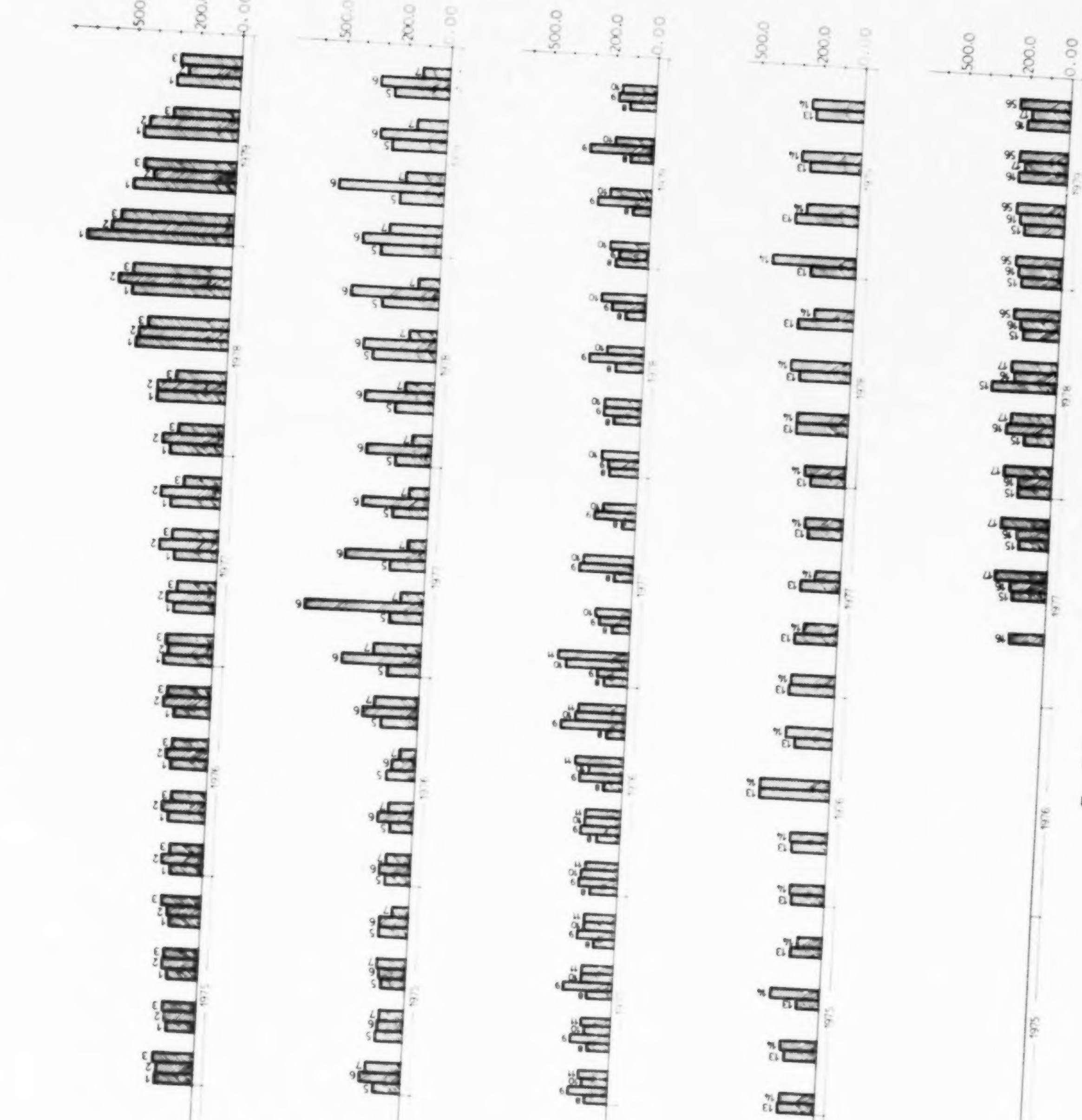
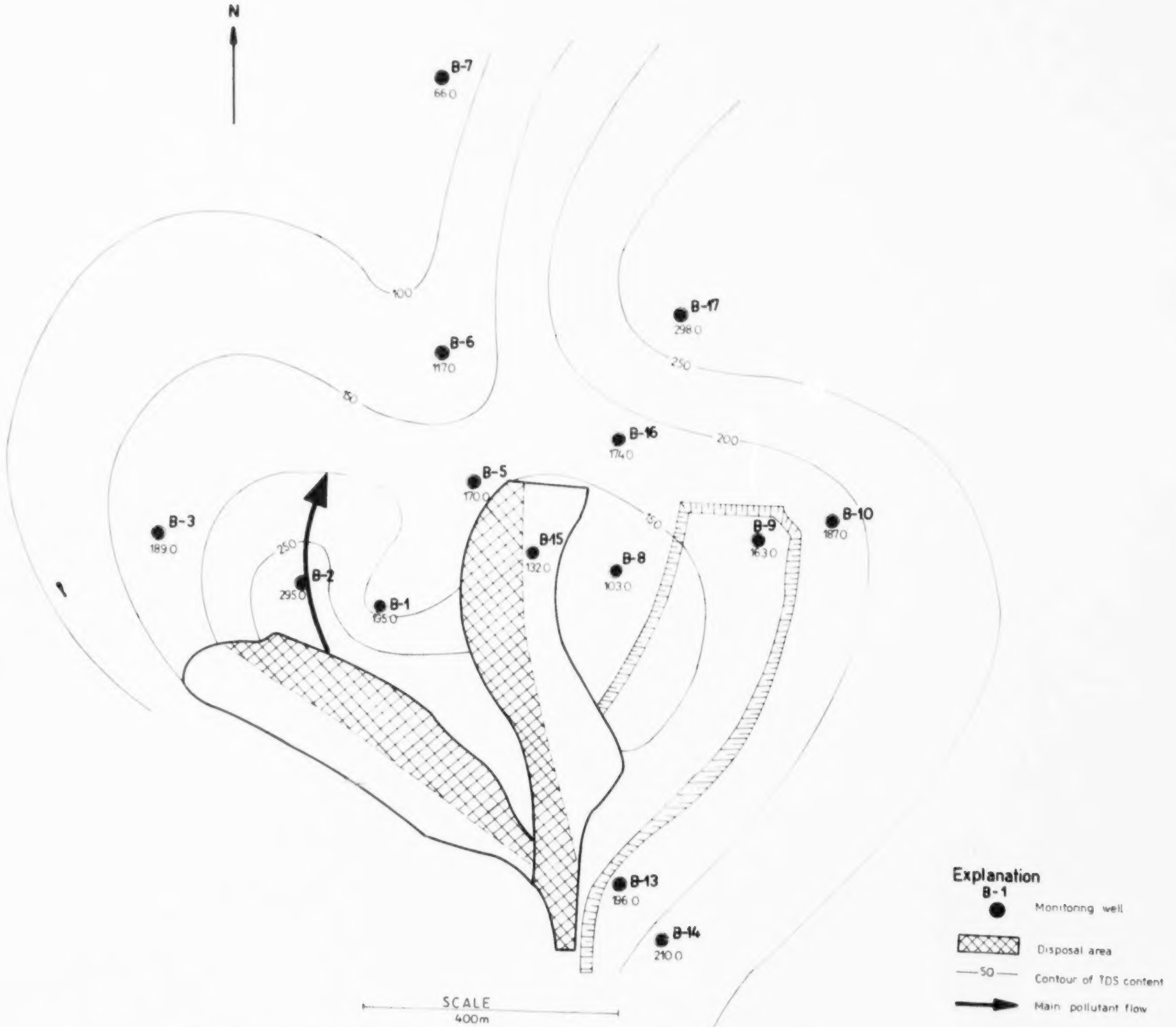


Fig. 9-3. The diagram of TDS content



N
B-7
66.0
100
B-6
117.0
150
B-17
298.0
250
B-16
174.0
200
B-5
170.0
B-3
189.0
250
B-2
295.0
B-1
155.0
B-15
132.0
B-8
103.0
150
B-9
163.0
B-10
187.0
B-13
196.0
B-14
210.0
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
50
Contour of TDS content
Main pollutant flow

Fig.9-4.THE MAP OF TDS DISTRIBUTION JULY 5. 1977

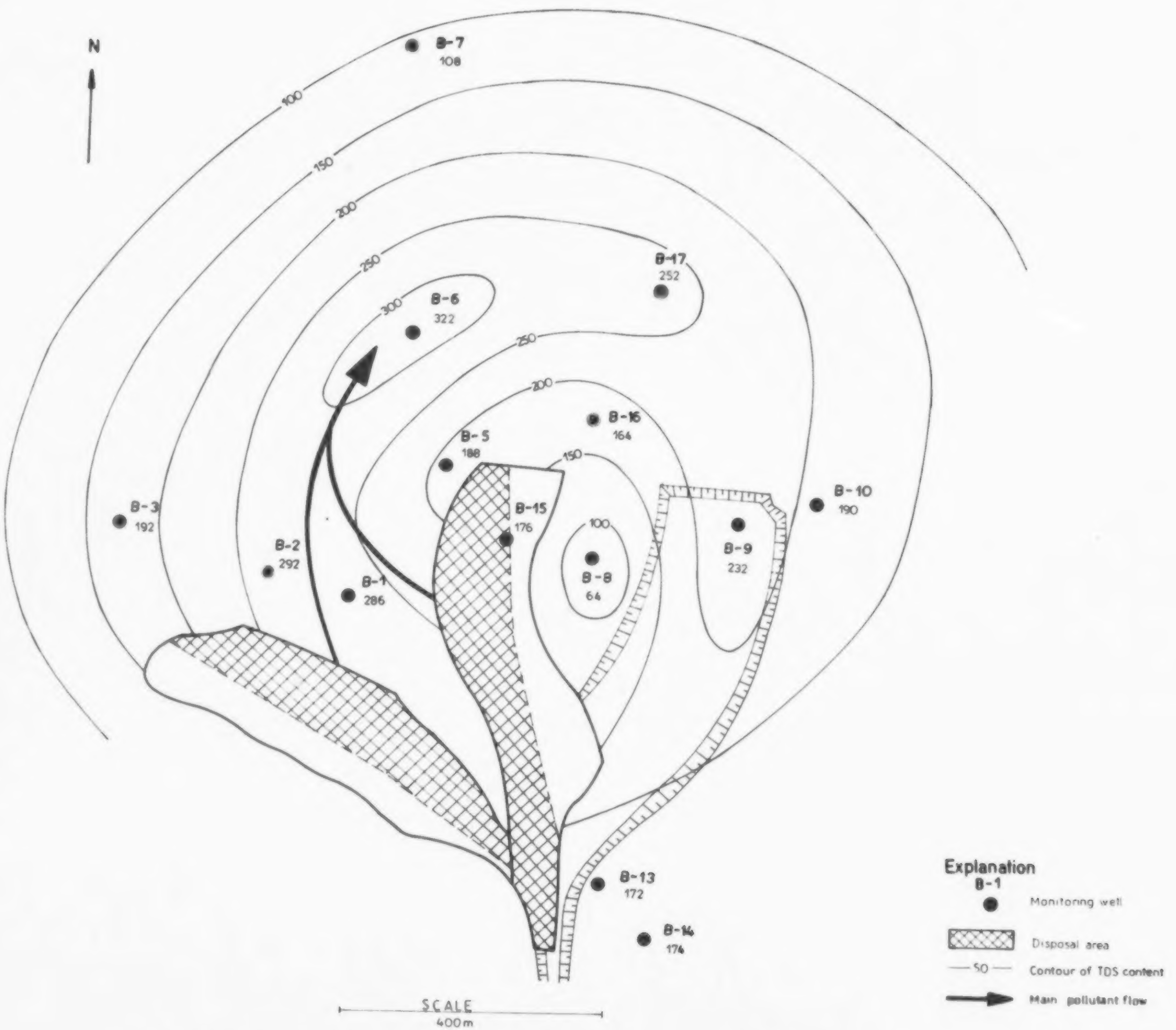

N
B-7
108
100
150
200
250
300
B-6
322
B-17
252
250
200
B-16
164
B-5
188
150
B-3
192
B-2
292
B-1
286
B-15
176
100
B-8
64
B-9
232
B-10
190
B-13
172
B-14
174
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
—50— Contour of TDS content
Main pollutant flow

Fig.9-5.THE MAP OF TDS DISTRIBUTION DECEMBER 20. 1977

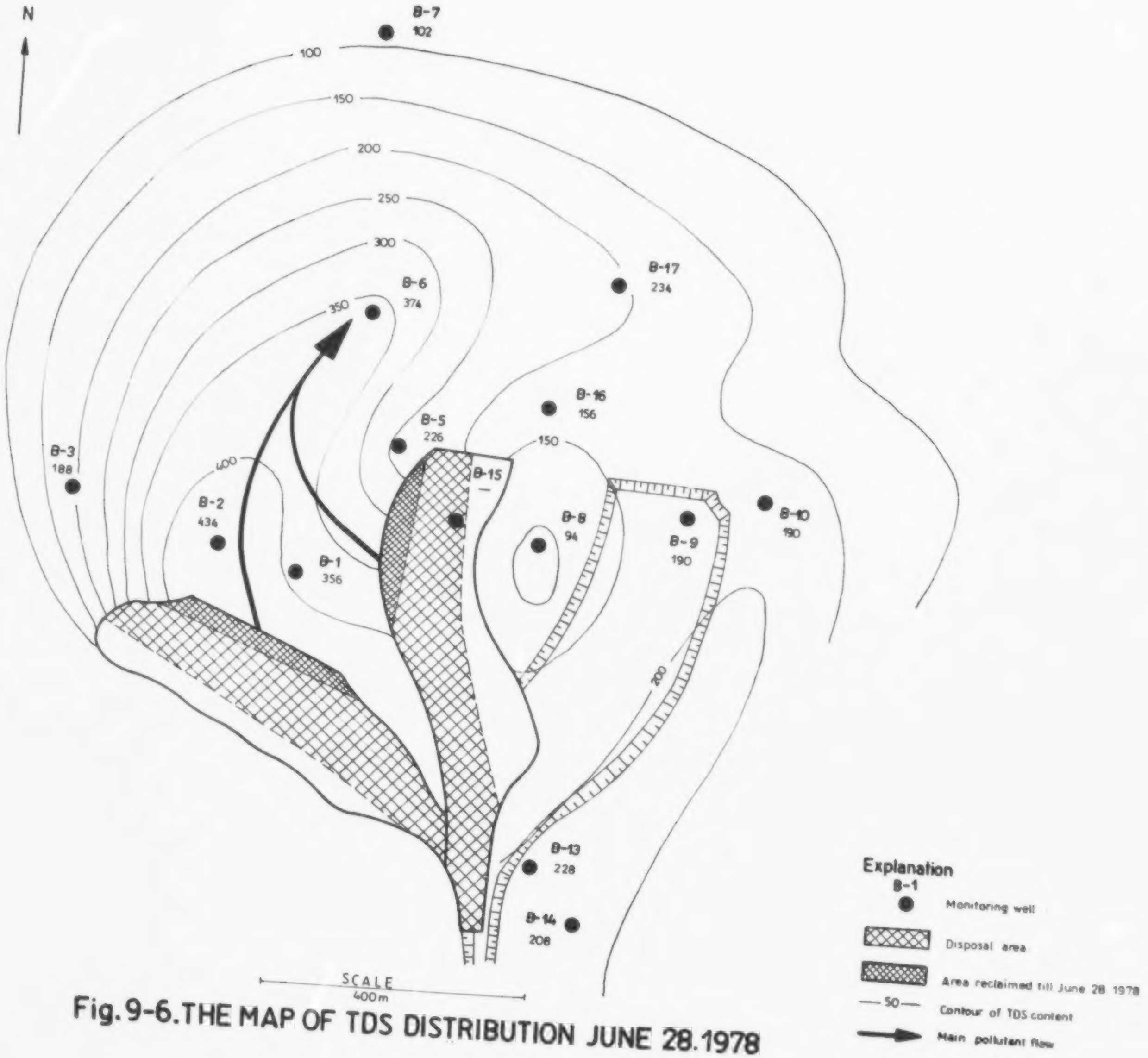
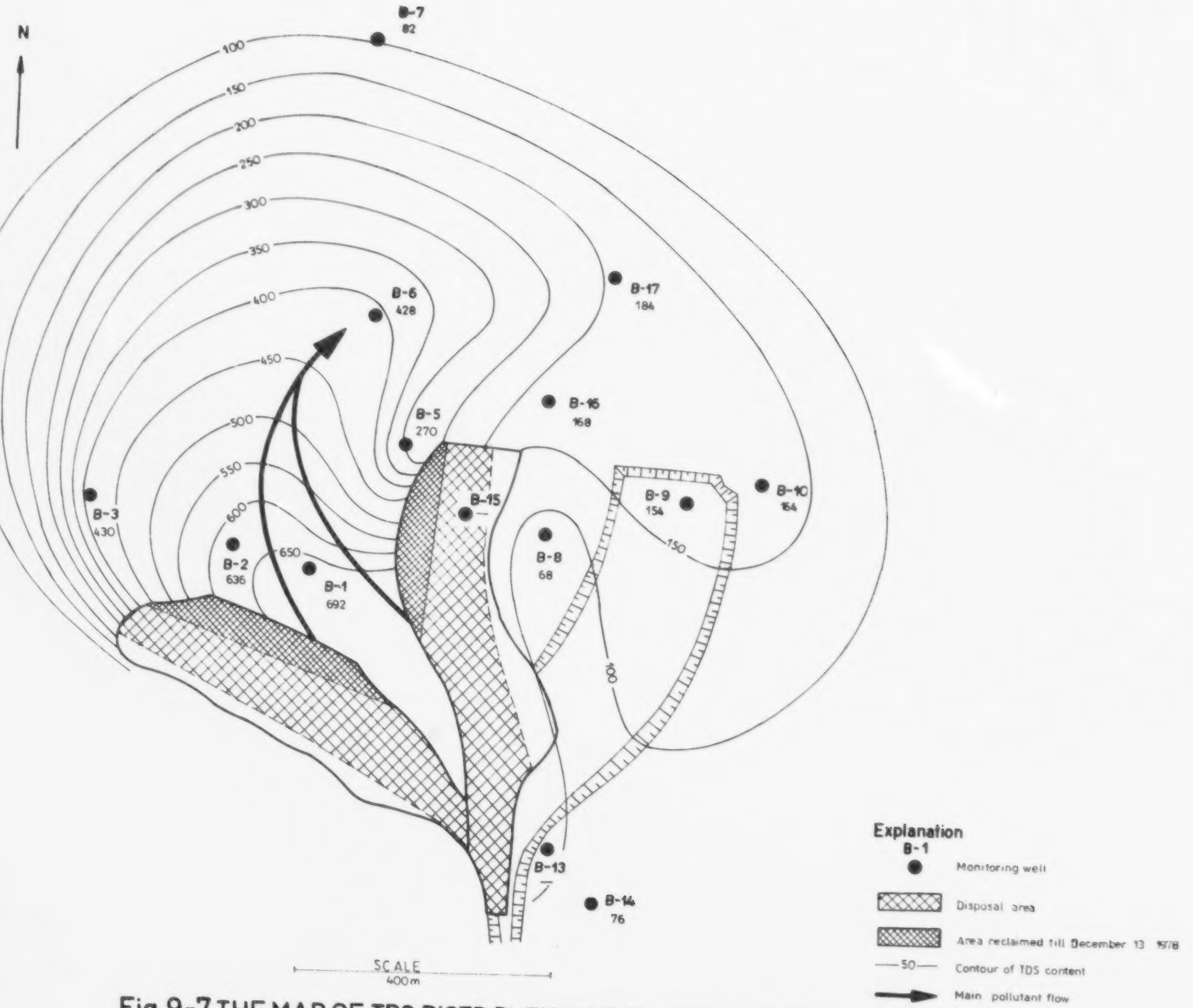

N
B-7
102
100
150
200
250
300
B-6
374
350
B-17
234
B-16
156
B-5
226
150
B-15
—
B-3
188
400
B-2
434
B-1
356
B-8
94
B-9
190
B-10
190
200
B-13
228
B-14
208
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
Area reclaimed till June 28 1978
—50— Contour of TDS content
Main pollutant flow

Fig. 9-6.THE MAP OF TDS DISTRIBUTION JUNE 28.1978



N
B-7
82
100
150
200
250
300
350
400
450
500
550
600
650
B-6
428
B-17
184
B-16
168
B-5
270
B-3
430
B-15
B-9
154
B-10
164
B-2
636
B-1
692
B-8
68
150
100
B-13
B-14
76
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
Area reclaimed till December 13 1978
—50— Contour of TDS content
Main pollutant flow

Fig.9-7.THE MAP OF TDS DISTRIBUTION DECEMBER 13. 1978

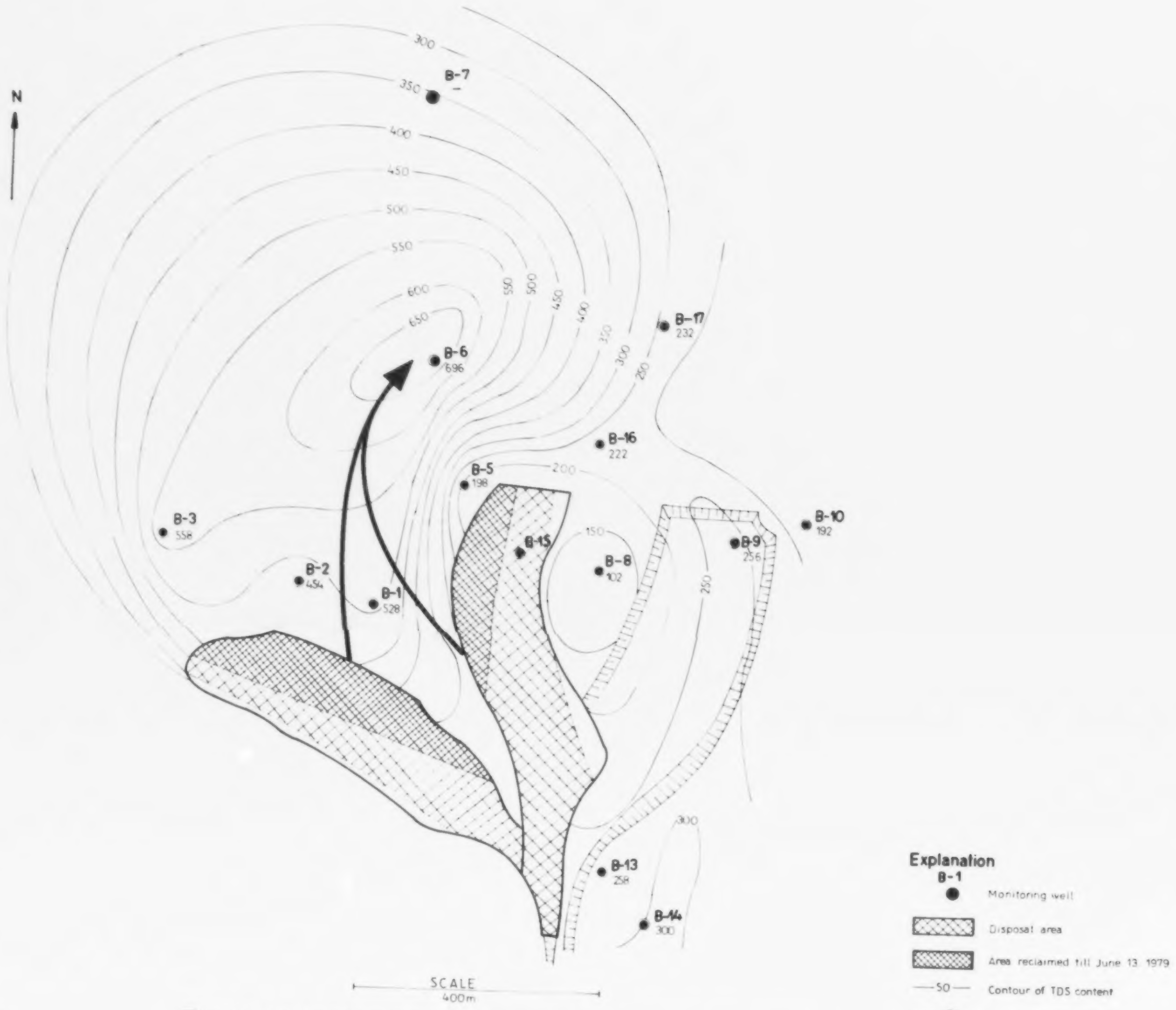

N
300
350
B-7
–
400
450
500
550
600
650
B-6
696
550
500
450
400
350
300
250
B-17
232
B-16
222
B-5
198
200
B-3
558
B-15
150
B-8
102
B-9
256
B-10
192
B-2
454
B-1
528
250
300
B-13
258
B-14
300
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
Area reclaimed till June 13. 1979
—50— Contour of TDS content
Main pollutant flow

Fig.9-8.THE MAP OF TDS DISTRIBUTION JUNE 13. 1979

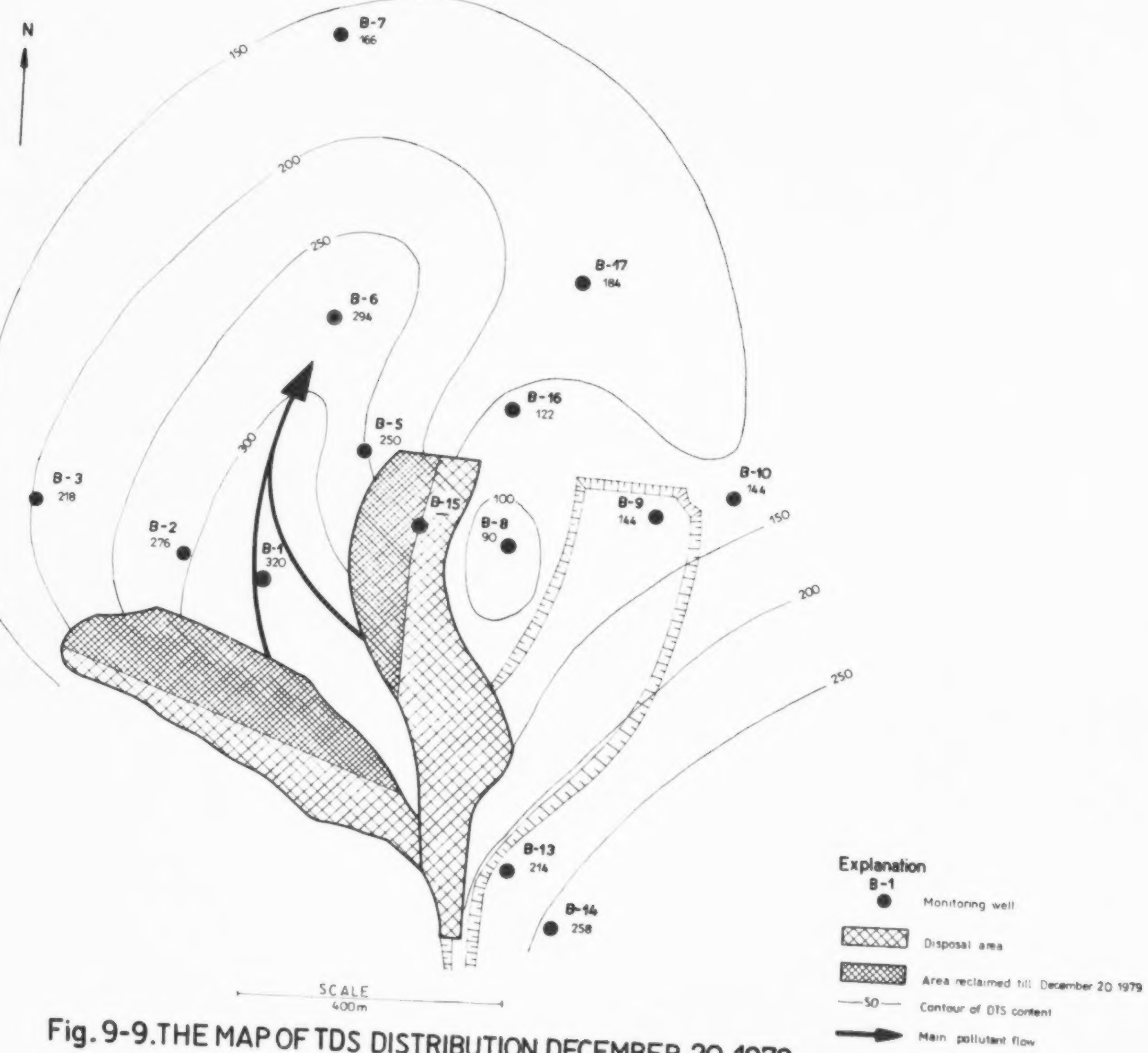

N
B-7
166
150
200
250
B-6
294
B-17
184
300
B-5
250
B-16
122
B-3
218
B-2
276
B-1
320
B-15
B-8
90
100
B-9
144
B-10
144
150
200
250
B-13
214
B-14
258
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
Area reclaimed till December 20 1979
50
Contour of DTS content
Main pollutant flow

Fig. 9-9.THE MAP OF TDS DISTRIBUTION DECEMBER 20.1979

Between 1977 and 1979, TDS content in other wells ranged from 100 to 300 mg/dm^3, corresponding to values observed before disposal.

It can be concluded that the clear effect of coal waste disposal appeared beginning in 1977 (two years after beginning storage) and was observed until June 1979, then it slightly decreased. The aquifer became polluted north of the disposal area, in the direction of groundwater flow, 200 to 300 m away.

However, no continuous increase of TDS content was observed in well B-5 which is located north of the site. This may prove that the pollutant's flow is not uniform and several underground streams (flumes) exist with varying contamination levels. The main factor is aquifer permeability. It was clearly stated that the main flume of pollution runs toward well B-6 which has a permeability 5 times higher than other surrounding wells except well B-5 which has low permeability.

Chloride (Cl)

The content of Cl in laboratory leachates varied from 51 to 479 mg/dm^3 (average 209 mg/dm^3). The content of chloride in groundwater before disposal operations began (1974) ranged from 6.6 mg/dm^3 (wells B-12 and B-13) to 39.7 mg/dm^3 (well B-12), with an average value of 20 mg/dm^3.

During the first period of waste disposal (1975-1976), chloride content in the groundwater did not differ from the concentrations observed before disposal operations; its average values were between 12 and 20 mg/dm^3.

At the beginning of 1977, the situation changed gradually. In February 1977, an increase in chloride (51 mg/dm^3) was first observed in well B-6, while in other wells it varied from 12 to 33 mg/dm^3. It gradually grew to a maximum of 96 mg/dm^3, observed in June 1979. Then the concentration decreased to between 20 and 40 mg/dm^3, which was still above the values found before disposal.

In May 1977, a high chloride concentration (41 mg/dm^3) was observed in well B-2 and until October 1978, it remained between 40 and 60 mg/dm^3. The chloride concentration gradually increased here and in March 1979 reached a maximum of 104 mg/dm^3. After that a gradual decrease of chloride to the level of 30 to 40 mg/dm^3 was observed (end of 1979).

In well B-1, chloride content increased to 40 to 60 mg/dm^3 between December 1977 and October 1978; then doubled and until the end of March 1979, remained at a level of 100 to 110 mg/dm^3. It gradually decreased to 35 to 45 mg/dm^3 by the end of 1979.

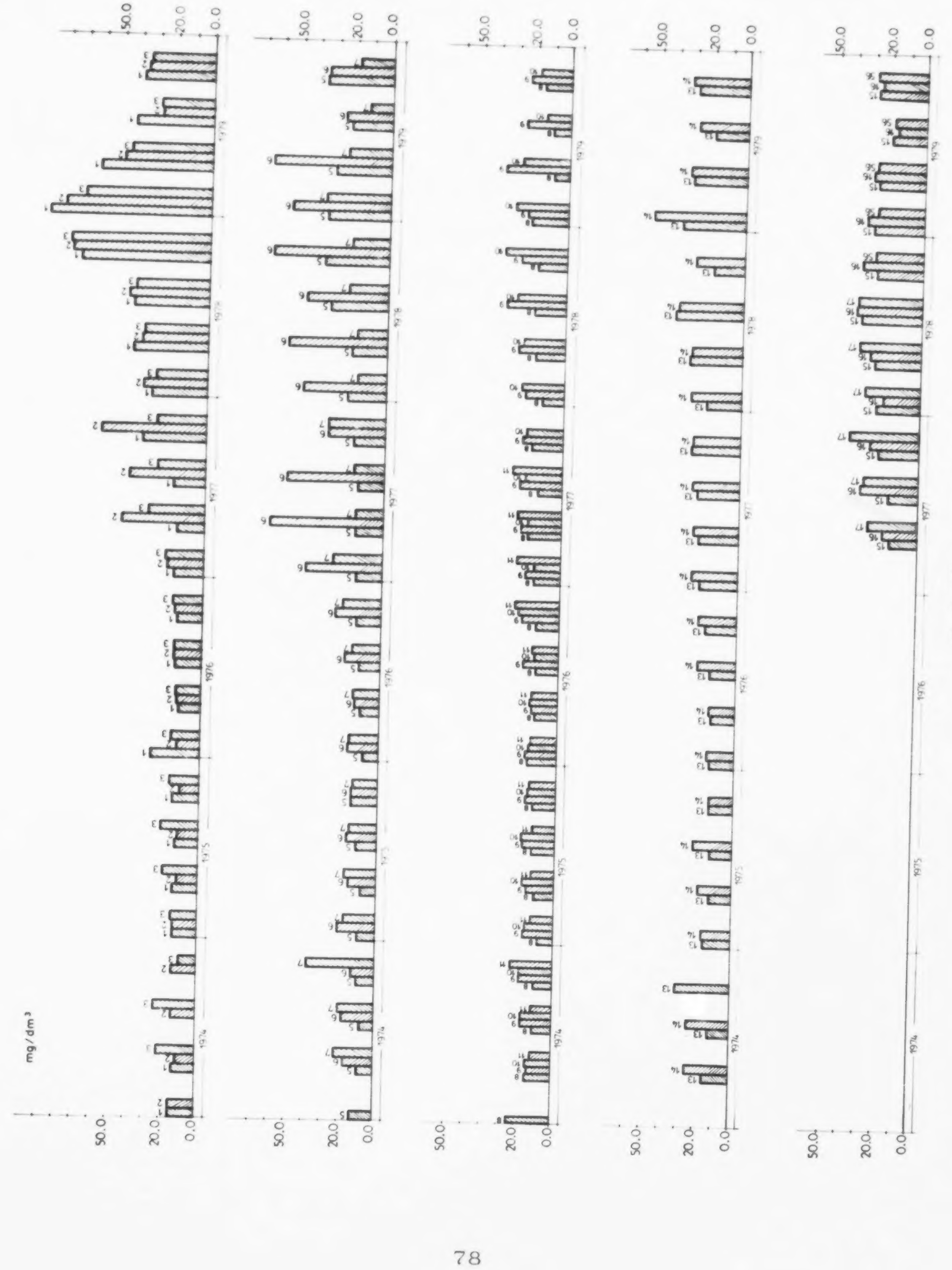
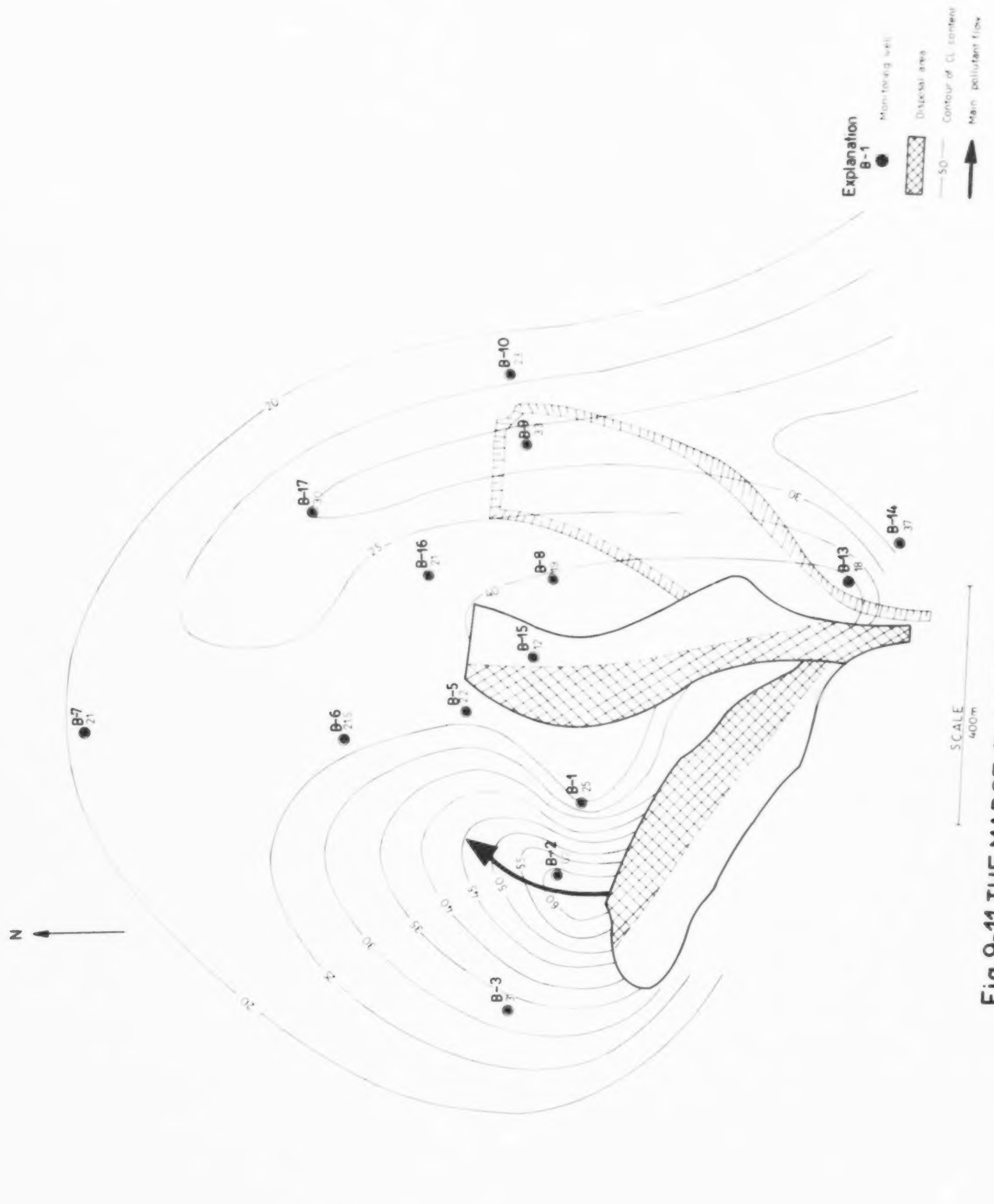


Fig.9-10.The diagram of Cl content



N
B-1
B-2
B-3
B-5
B-6
B-7
B-8
B-9
B-10
B-13
B-14
B-15
B-16
B-17
20
25
30
35
40
45
50
55
60
SCALE
400m
Explanation
B-1 ● Monitoring well
▨ Disposal area
—50— Contour of CL content
Main pollutant flow

Fig.9-11.THE MAP OF CL DISTRIBUTION JULY 5. 1977

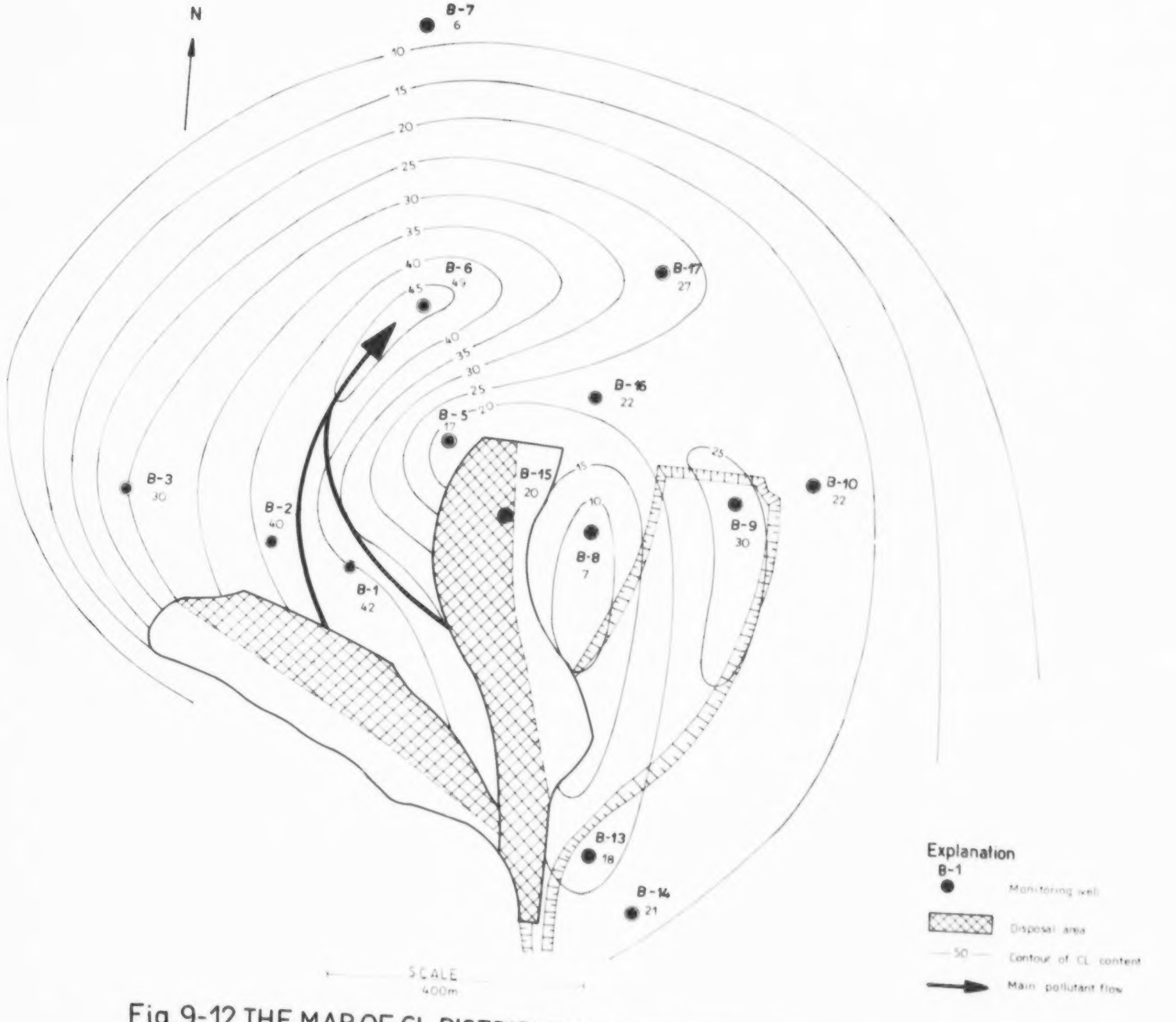

N
B-7
6
B-6
49
B-17
27
B-16
22
B-5
17
B-15
20
B-3
30
B-2
40
B-1
42
B-8
7
B-9
30
B-10
22
B-13
18
B-14
21
10
15
20
25
30
35
40
45
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
50
Contour of CL content
Main pollutant flow

Fig.9-12.THE MAP OF CL DISTRIBUTION DECEMBER 20. 1977

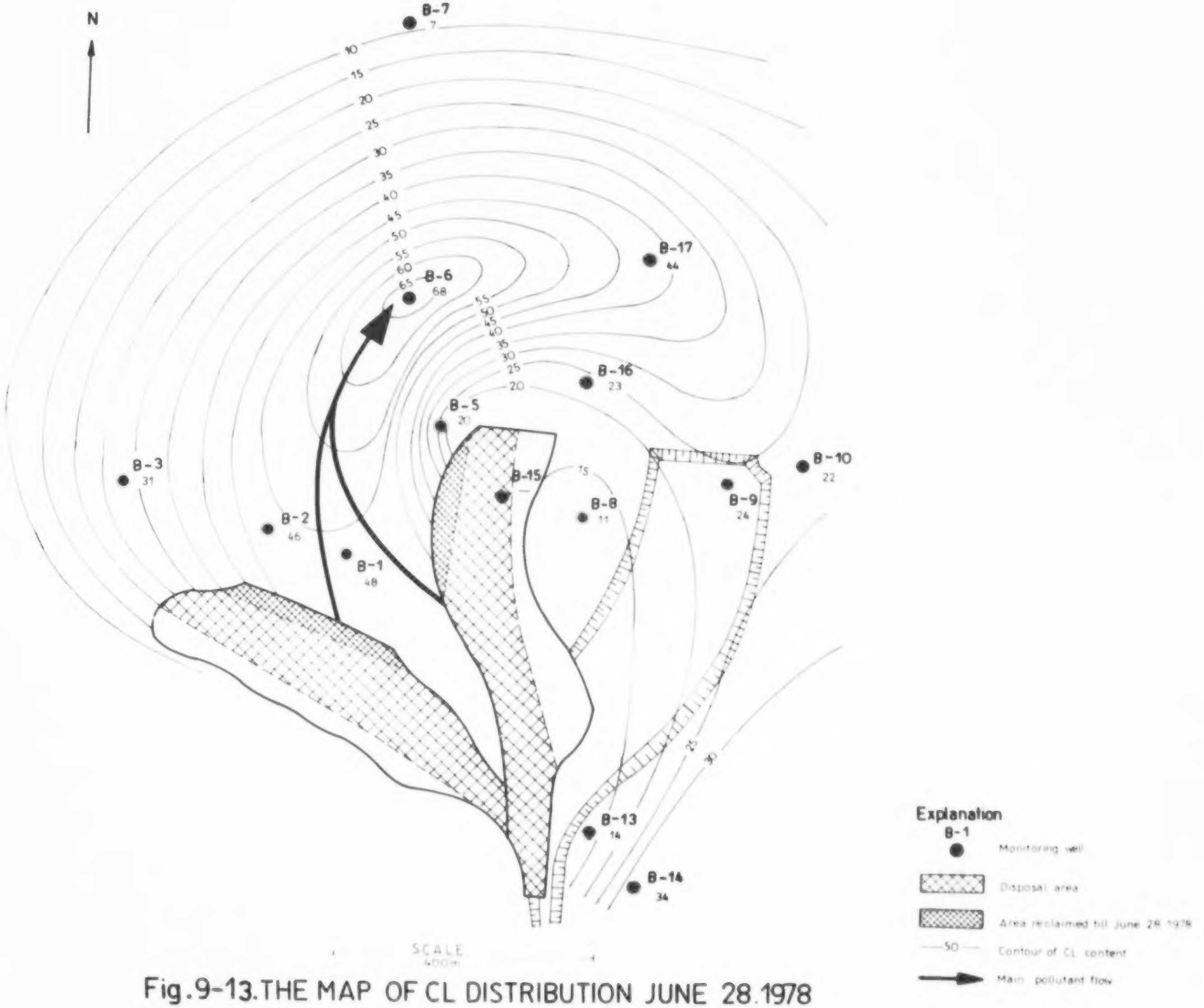

N
B-7
7
B-17
44
B-6
68
B-16
23
B-5
20
B-15
B-8
11
B-9
24
B-10
22
B-3
31
B-2
46
B-1
48
B-13
14
B-14
34
10
15
20
25
30
35
40
45
50
55
60
65
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
Area reclaimed till June 28 1978
—50— Contour of CL content
Main pollutant flow

Fig.9-13.THE MAP OF CL DISTRIBUTION JUNE 28.1978

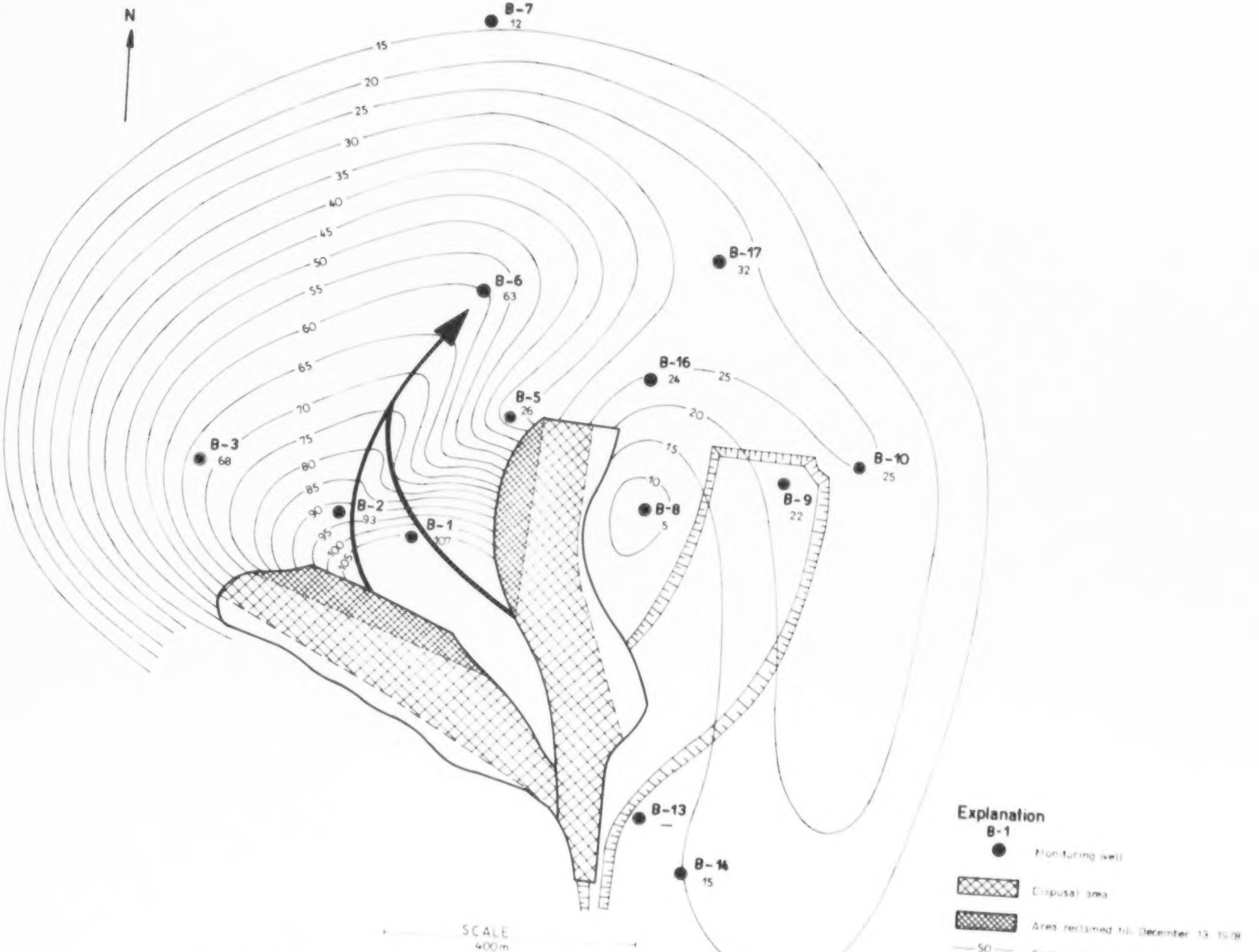

N
B-7 12
B-6 63
B-5 26
B-3 68
B-2 93
B-1 107
B-16 24
B-17 32
B-8 5
B-9 22
B-10 25
B-13 —
B-14 15
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
10
15
20
25
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
Area reclaimed till December 13. 1978
50
Contour of CL content
Main pollutant flow

Fig. 9-14. THE MAP OF CL DISTRIBUTION DECEMBER 13. 1978

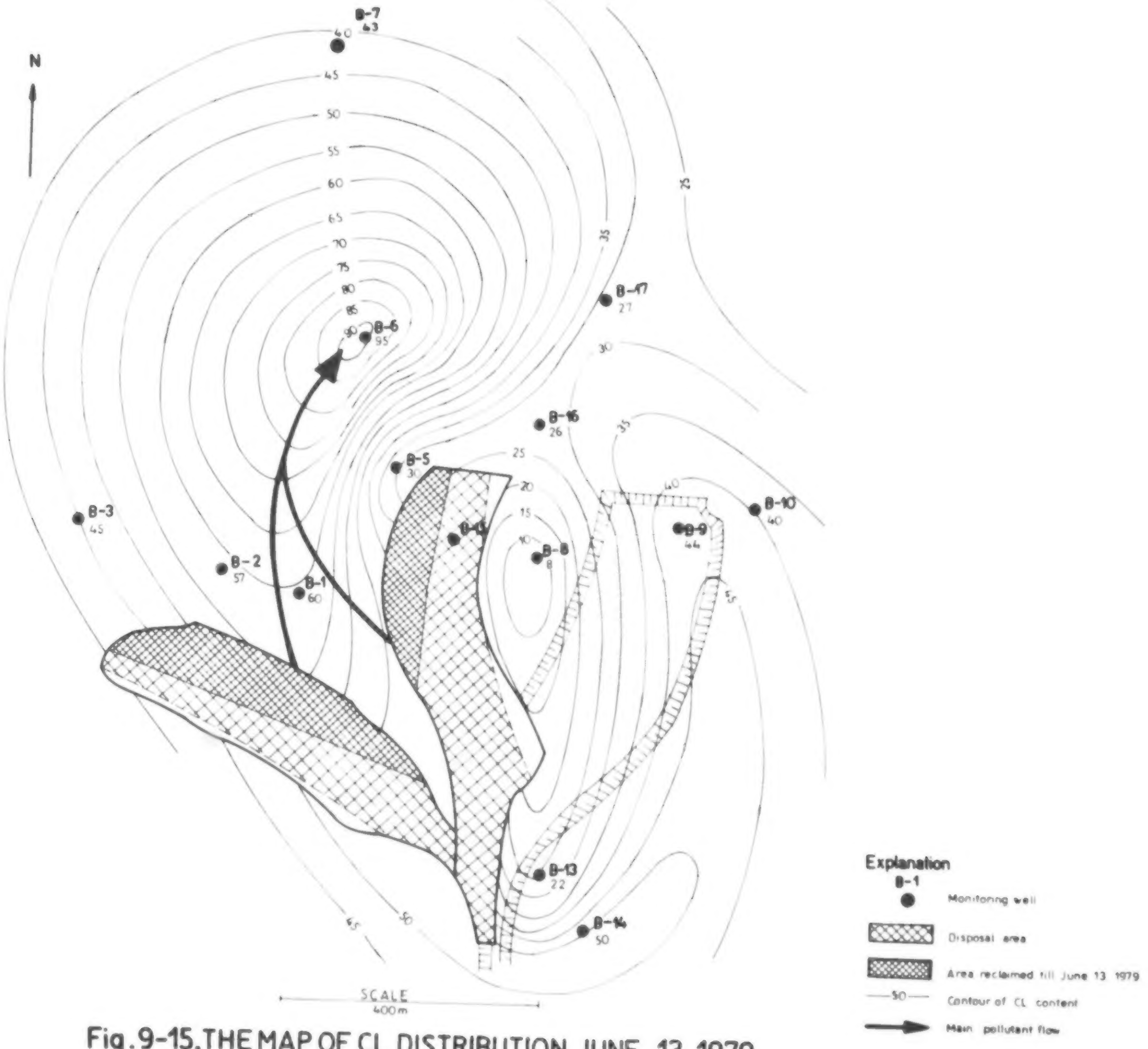

N
B-7
43
B-6
95
B-17
27
B-16
26
B-5
30
B-8
8
B-9
44
B-10
40
B-3
45
B-2
57
B-1
60
B-13
22
B-14
50
25
30
35
40
45
50
55
60
65
70
75
80
85
90
20
15
10
SCALE
400m
Explanation
B-1
● Monitoring well
Disposal area
Area reclaimed till June 13 1979
—50— Contour of CL content
Main pollutant flow

Fig. 9-15. THE MAP OF CL DISTRIBUTION JUNE 13. 1979

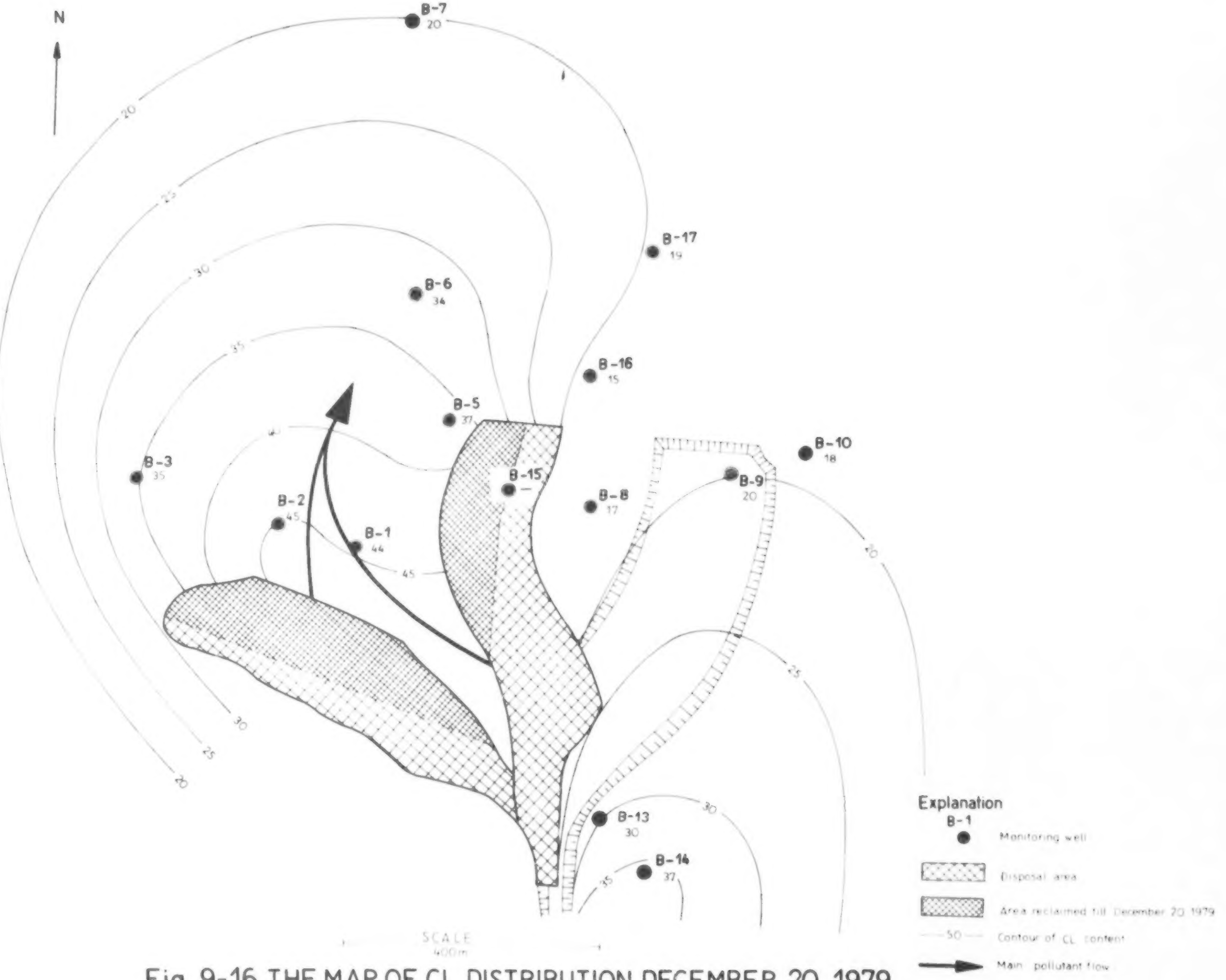

N
B-7
20
B-17
19
B-6
34
B-16
15
B-5
37
B-10
18
B-3
35
B-15
—
B-9
20
B-8
17
B-2
45
B-1
44
B-13
30
B-14
37
20
25
30
35
40
45
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
Area reclaimed till December 20 1979
50
Contour of CL content
Main pollutant flow

Fig. 9-16.THE MAP OF CL DISTRIBUTION DECEMBER 20. 1979

The first indications of increased chloride in well B-3 appeared in January 1978 (52 mg/dm^3) and from then until September 1978, it usually varied from 30 to 40 mg/dm^3. From October 1978 the chloride content increased to a maximum of 110 mg/dm^3 in March 1979. Then it rapidly dropped to 35 to 40 mg/dm^3 and remained there until the end of 1979.

Less significant increases were observed in wells B-5, B-16 and B-17 (43 to 49 mg/dm^3 in June 1978).

In the other wells chloride content varied from 15 to 30 mg/dm^3.

It can be concluded that coal waste disposal affected the content of chlorides in the groundwater. These changes were noted beginning in 1977, i.e., two years after disposal operations had begun. The concentration of chlorides reached maximum levels (2-5 times higher) after two and a half years, and beginning in mid 1979, the chloride content decreased significantly. The polluted area extended 200 to 300 m to the north of the disposal site in the direction of the groundwater flow. No influence was observed in the wells sited on the smaller inclinations of the groundwater table or where no dipping was observed.

Sulphate (SO_4)

The content of sulphate in laboratory leachates varied from 50 to 230 mg/dm^3 (the average was 164.5 mg/dm^3). Before disposal operations began in 1974, sulphate content in groundwater was from 40 mg/dm^3 (wells B-10, B-8) to 150 mg/dm^3 (well B-3). During the first period of disposal operations (1975-1976) SO_4 content in groundwater did not change significantly. In all wells it was slightly lower than in 1974 and ranged from 10 mg/dm^3 (wells B-5, B-6, B-7) to 125 mg/dm^3 (wells B-9, B-12).

At the beginning of 1977, the situation began to change. In January 1977 the content of SO_4 increased in well B-1 (84.0 mg/dm^3) and in well B-6 (87.0 mg/dm^3), while at the same time other wells showed levels from 40 to 60 mg/dm^3.

In 1977 and during the first three months of 1978, the SO_4 content in well B-1 remained generally at a level of 80 to 110 mg/dm^3. In April 1978, a gradual increase of SO_4 was noted and it reached a maximum level of 404 mg/dm^3 in March 1979. In April 1979, the SO_4 content gradually decreased. From April until September the sulphate content was between 200 and 300 mg/dm^3 and in October it dropped to 85 to 95 mg/dm^3 and remained there until the end of the investigation.

In 1977 and 1978, the SO_4 content in well B-6 varied from 90 to 130 mg/dm^3. Between January and May 1979 SO_4 increased up to a maximum value of 240 mg/dm^3 (observed in May 1979). From then until August 1979 the SO_4 content gradually decreased, first to 120 mg/dm^3 and then to 70 to 90 mg/dm^3, where it remained through the end of the project period.

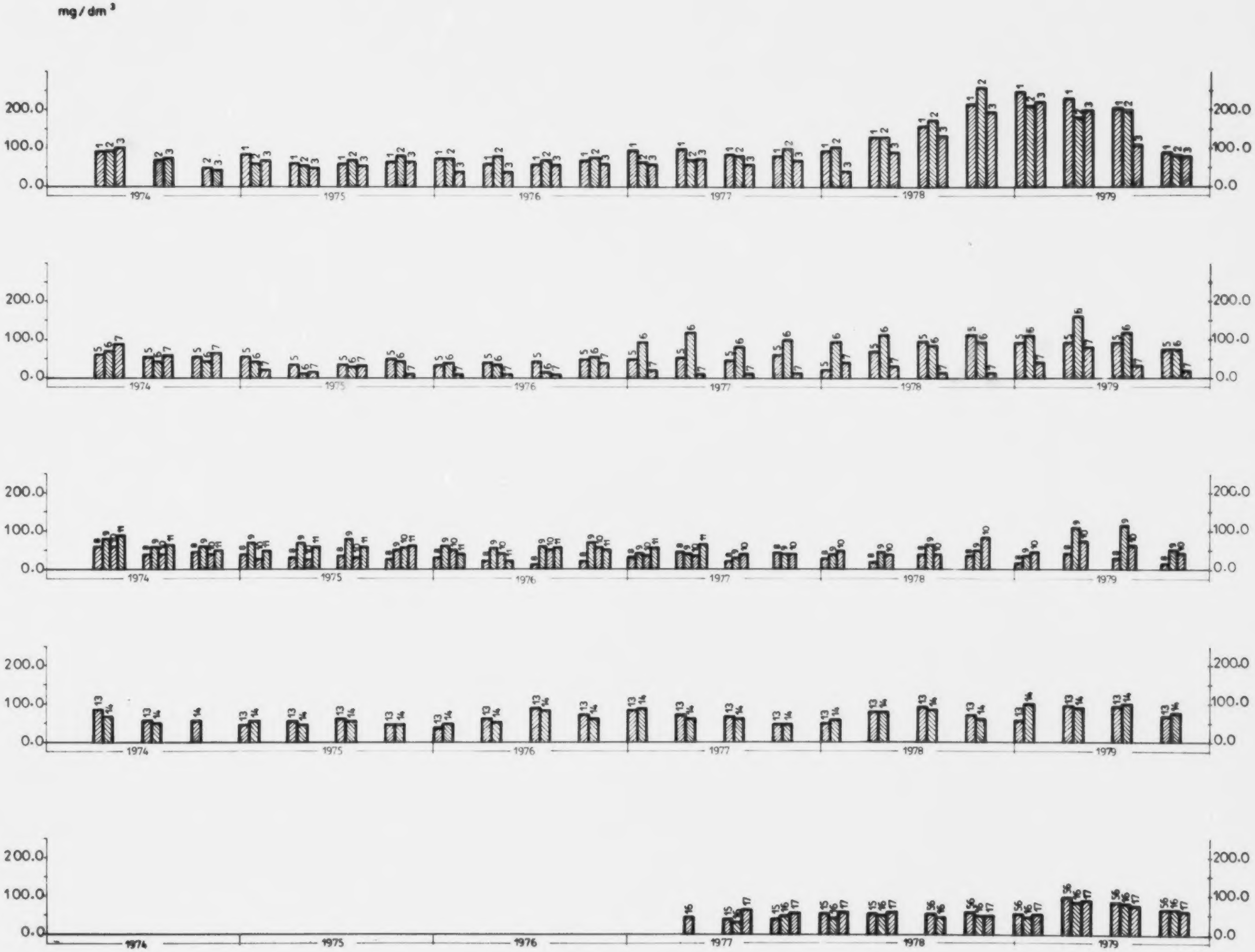


Fig. 9-17. The diagram of SO₄ content

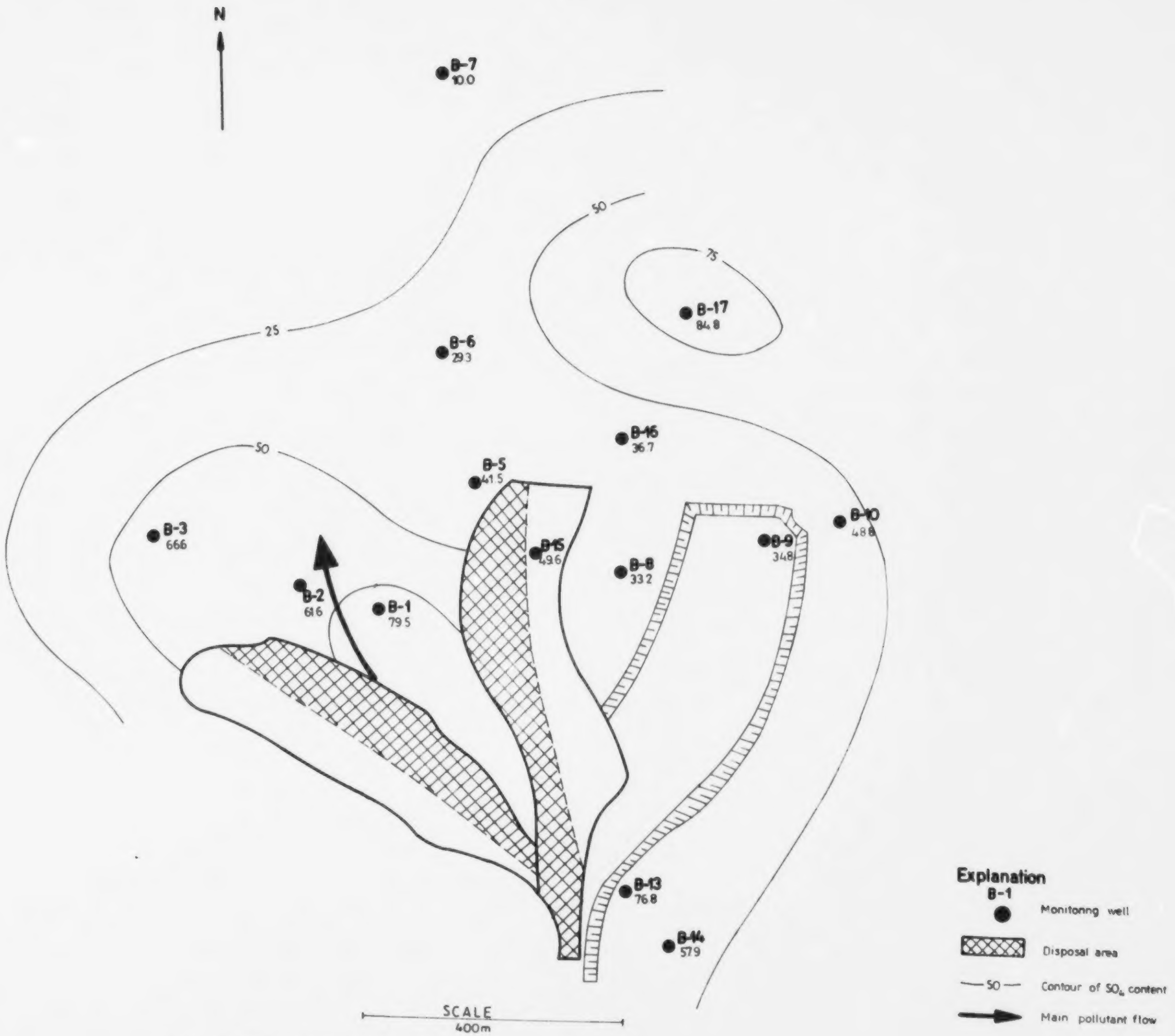

N
B-7
10.0
B-6
29.3
B-17
84.8
B-16
36.7
B-5
41.5
B-15
49.6
B-8
33.2
B-9
34.8
B-10
48.8
B-3
66.6
B-2
61.6
B-1
79.5
B-13
76.8
B-14
57.9
25
50
50
75
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
— 50 — Contour of SO_4 content
Main pollutant flow

Fig. 9-18. THE MAP OF SO_4 DISTRIBUTION JULY 5. 1977

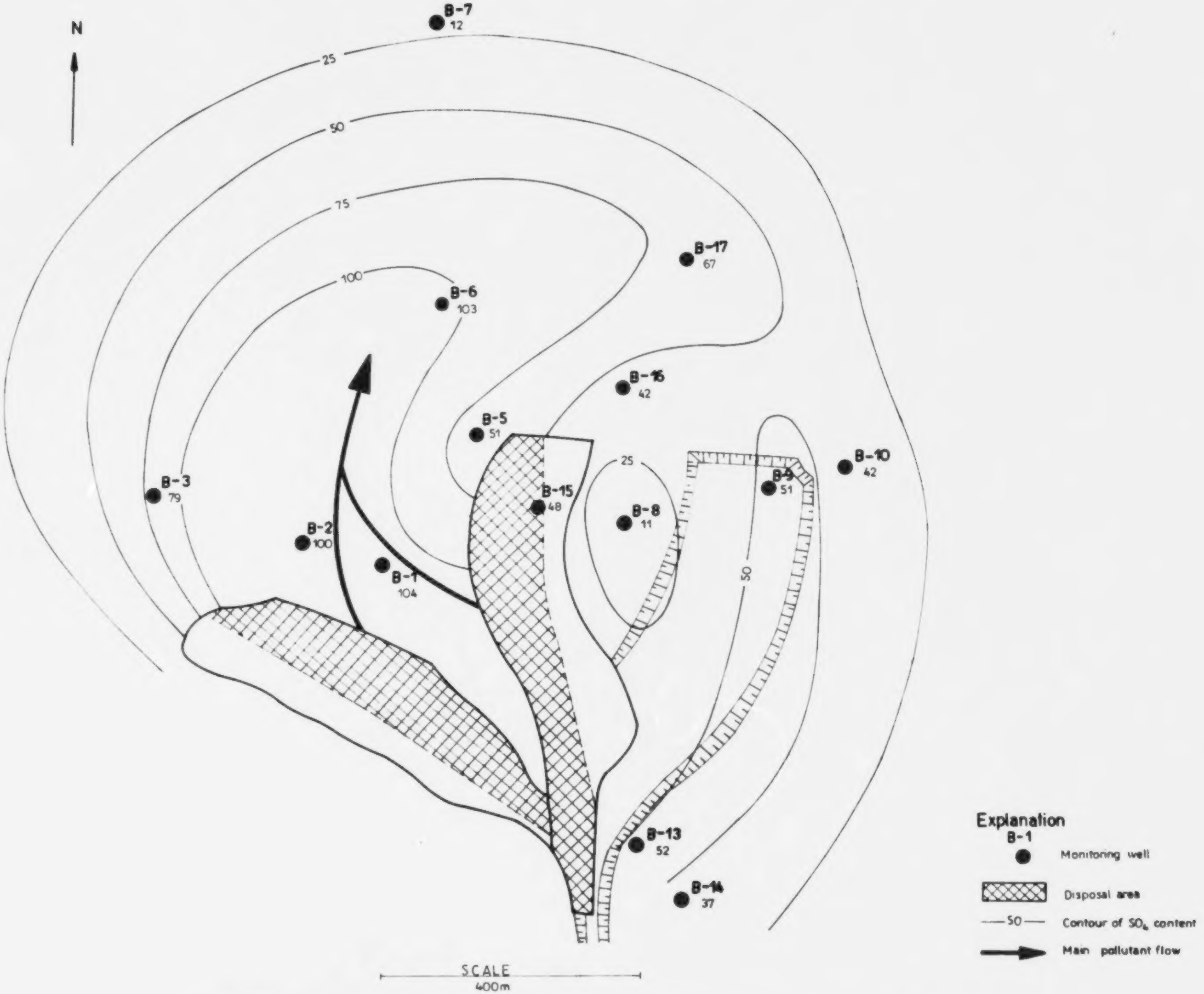
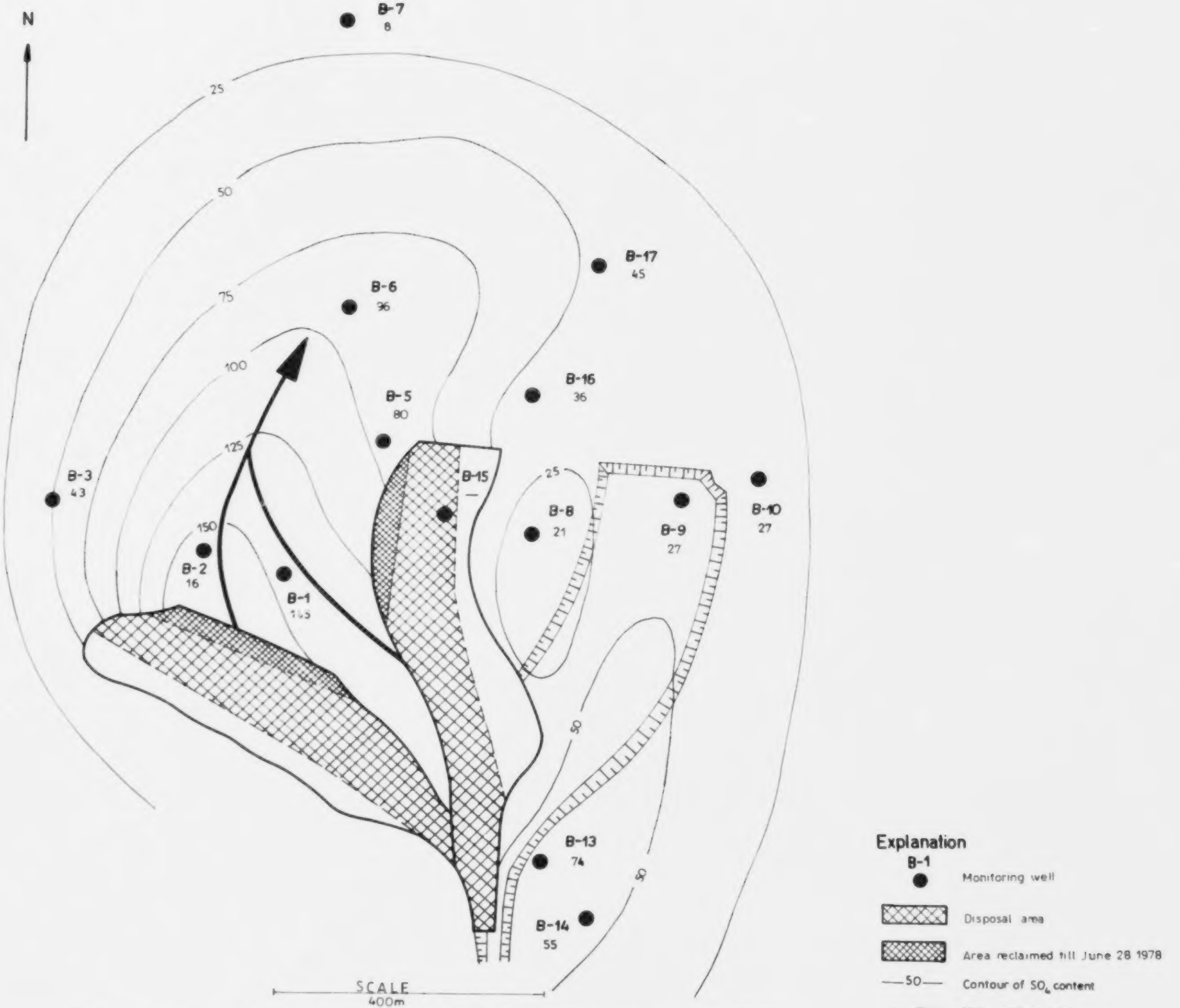
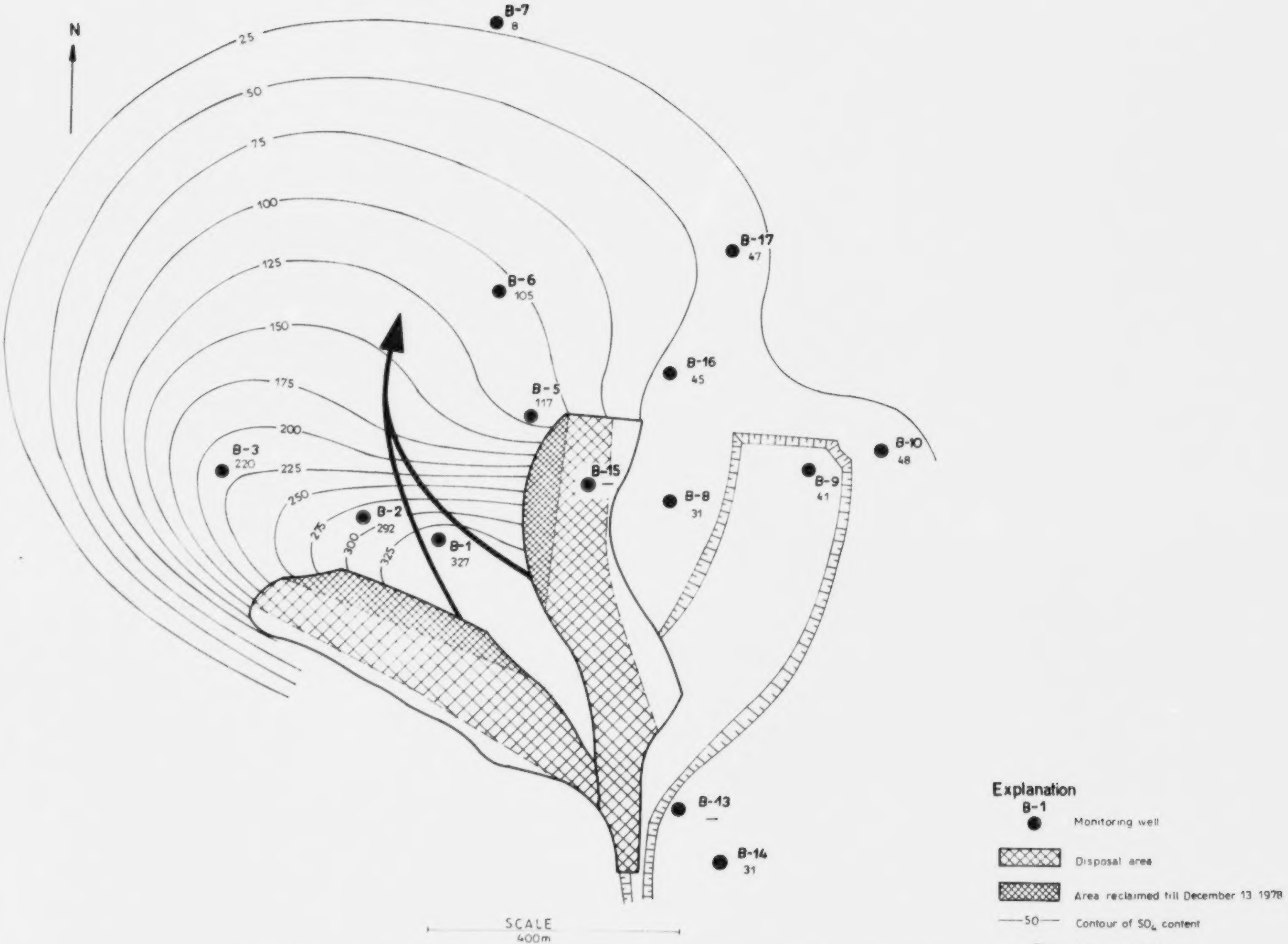

N
B-7
12
25
50
75
100
B-6
103
B-17
67
B-16
42
B-5
51
B-3
79
B-2
100
B-1
104
B-15
48
25
B-8
11
B-9
51
B-10
42
50
B-13
52
B-14
37
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
—50— Contour of SO_4 content
Main pollutant flow

Fig.9-19.THE MAP OF SO_4 DISTRIBUTION DECEMBER 20.1977



N
B-7
8
B-17
45
B-6
96
B-16
36
B-5
80
B-3
43
B-15
—
B-8
21
B-9
27
B-10
27
B-2
16
B-1
145
B-13
74
B-14
55
25
50
75
100
125
150
25
50
50
SCALE
400m
Explanation
B-1
● Monitoring well
▨ Disposal area
▩ Area reclaimed till June 28 1978
—50— Contour of SO_4 content
Main pollutant flow

Fig.9-20.THE MAP OF SO_4 DISTRIBUTION JUNE 28.1978



N
25
50
75
100
125
150
175
200
225
250
275
300
325
B-7
8
B-6
105
B-5
117
B-3
220
B-2
292
B-1
327
B-15
—
B-16
45
B-17
47
B-8
31
B-9
41
B-10
48
B-13
—
B-14
31
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
Area reclaimed till December 13 1978
50
Contour of SO4 content
Main pollutant flow

Fig.9-21. THE MAP OF SO_4 DISTRIBUTION DECEMBER 13. 1978

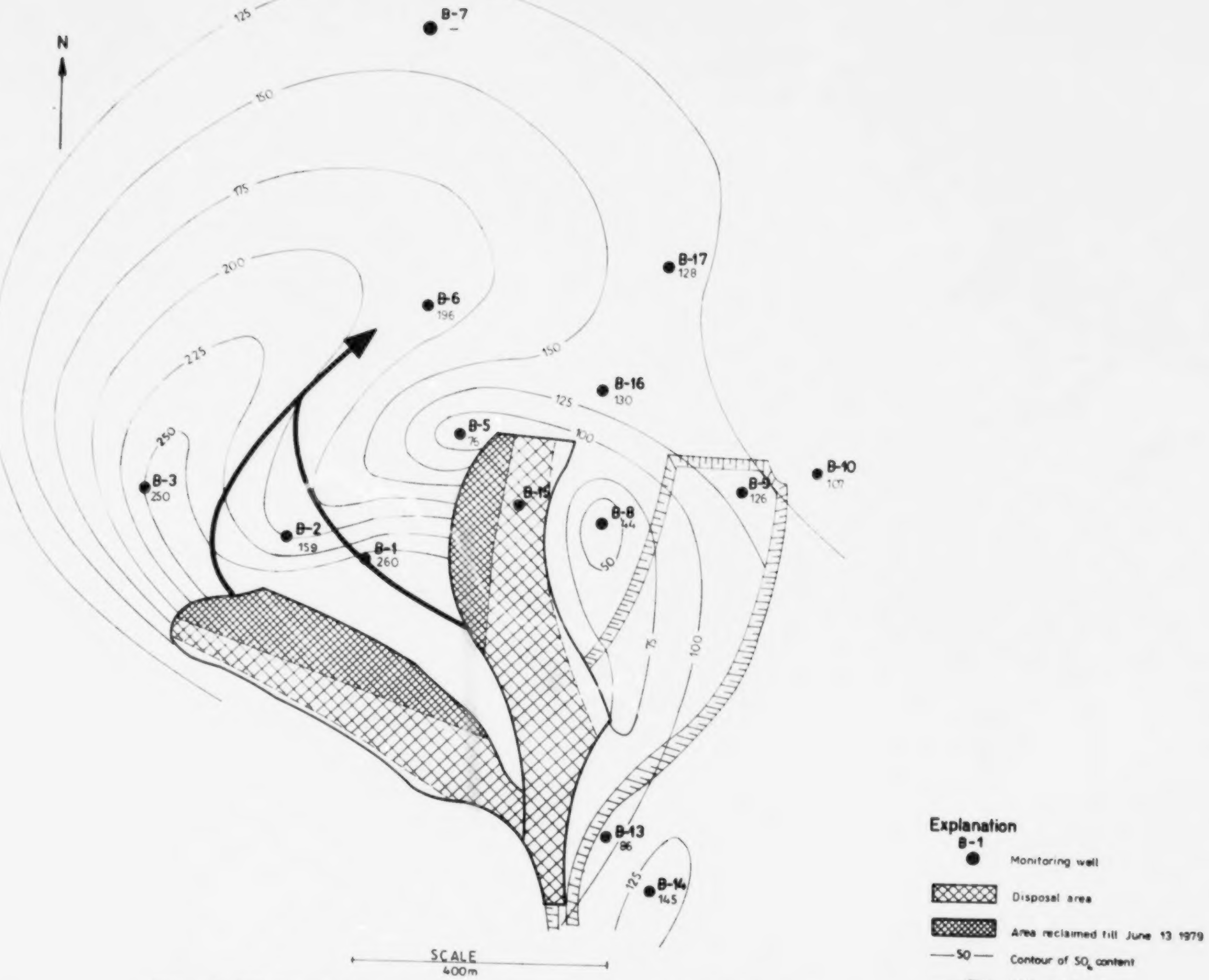

N
B-7
–
B-17
128
B-6
196
B-16
130
B-5
76
B-15
B-8
44
B-9
126
B-10
107
B-3
250
B-2
159
B-1
260
B-13
86
B-14
145
125
150
175
200
225
250
100
75
50
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
Area reclaimed till June 13 1979
—50— Contour of SO₄ content
Main pollutant flow

Fig. 9-22. THE MAP OF SO_4 DISTRIBUTION JUNE 13. 1979

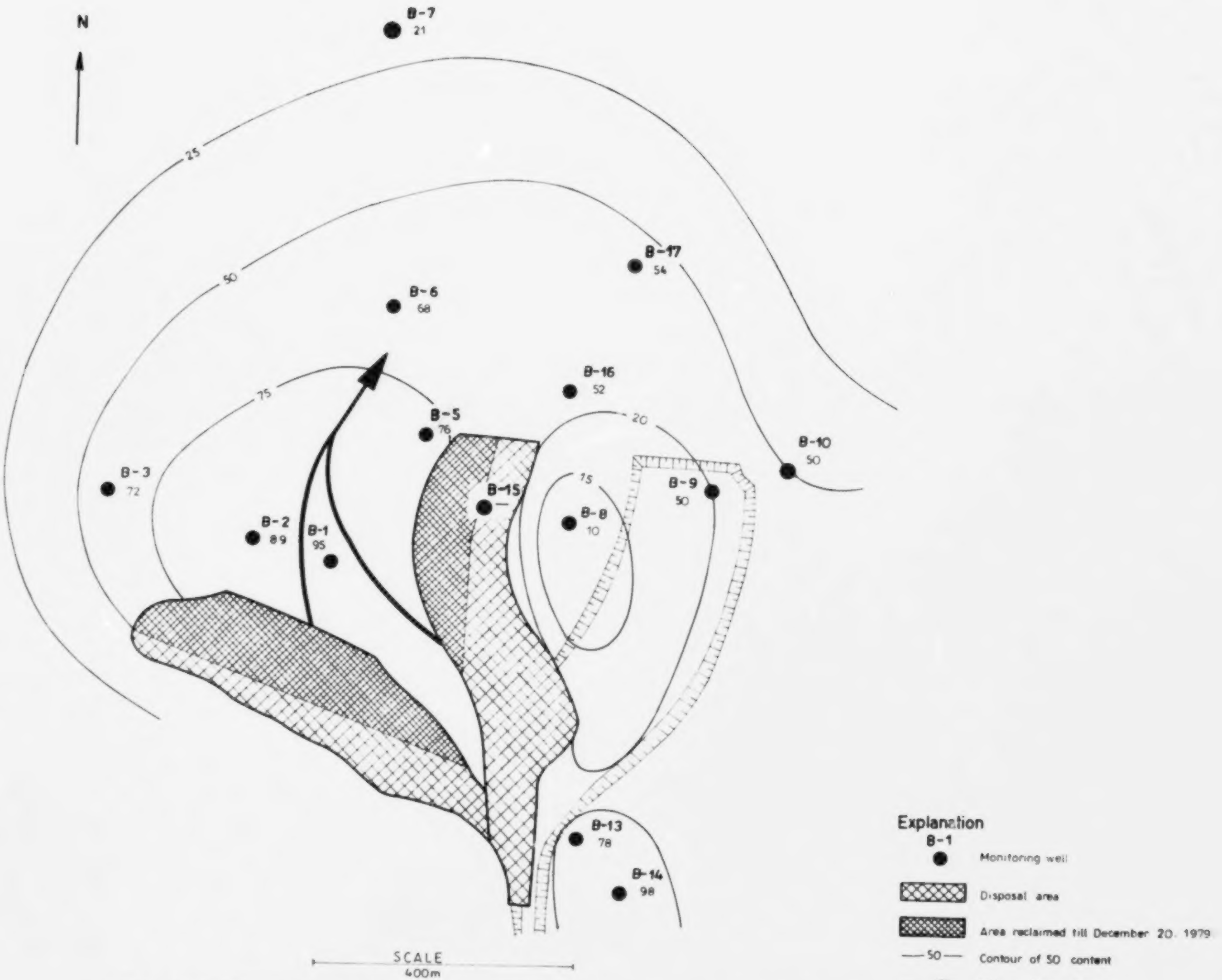

N
B-7
21
25
50
B-17
54
B-6
68
B-16
52
75
B-5
76
20
B-10
50
B-3
72
B-15
—
15
B-9
50
B-8
10
B-2
89
B-1
95
B-13
78
B-14
98
SCALE
400m
Explanation
B-1
Monitoring well
Disposal area
Area reclaimed till December 20. 1979
—50— Contour of SO content
Main pollutant flow

Fig.9-23.THE MAP OF SO_4 DISTRIBUTION DECEMBER 20. 1979

An increased SO_4 content was also observed in well B-2. The level remained at 90 to 120 mg/dm^3 until March 1978 when it gradually increased to a maximum of 350 mg/dm^3 (observed in March 1979). The content of SO_4 gradually decreased to a value of 200 to 250 mg/dm^3. In August 1979, it rapidly dropped to 80 to 90 mg/dm^3 and remained there until the completion of the investigation.

Increased SO_4 content appeared also in well B-3 in 1977 for a short time (April - 108 mg/dm^3 and October - 97 mg/dm^3). A continuous increase of SO_4 was observed here from March 1978 (90 mg/dm^3) until March 1979 (maximum 370 mg/dm^3). During the next five months, until August 1979, SO_4 content gradually lessened but remained at greater than normal levels, between 150 and 250 mg/dm3. After August 1979 it slowly decreased to 70 mg/dm^3, the level observed at the end of 1979.

In well B-5 increased values were found between July 1978 and May 1979. During this period SO_4 content varied from 100 to 120 mg/dm^3 except in July 1978 when it reached 153 mg/dm^3. It dropped again and in most cases remained between 70 and 95 mg/dm^3.

In all the above wells irregular decreases in sulphate content were found for short periods of time.

The SO_4 content in other wells sometimes fluctuated considerably, but most often did not exceed 50 to 100 mg/dm^3. Independent of pollution attributed to the disposal operations, singular episodes of high SO_4 concentrations were noted in wells B-14 (145 mg/dm^3), B-16 (130 mg/dm^3 in June 1979), B-13 (153 mg/dm^3 in May 1979) and in others. These phenomena were most probably caused by sources other than the disposal site.

In view of the above results, it may be concluded that the significant increase in SO_4 content in the groundwater was caused by the disposal site. Its influence was evident between 1977 and 1979 in the section of aquifer situated 200 to 300 m north of the disposal site, i.e. downstream.

Sodium (Na)

The content of Na in laboratory leachates varied from 44.5 - 357 mg/dm^3, averaging 243.7 mg/dm^3. In 1974, its concentrations in groundwater were from 4.45 mg/dm^3 (well B-11) to 31.1 mg/dm^3 (well B-3). During 1975 and 1976, the first years of disposal operations, the value did not show any changes as compared to the previous years. The Na content was at the level observed in 1974 and varied from 5 to 15 mg/dm^3.

In 1977 Na content in groundwater began to change. Between March and May and in July, the value found in well B-6 was higher than previously recorded (22 to 27 mg/dm^3), and in well B-2 during February, July, September and October it was about 20 to 25 mg/dm^3. Otherwise, the Na content did not exceed 15 mg/dm^3.

Higher and more regular increases of Na were observed in more wells beginning in 1978. Between March and December 1978, Na content in well B-6 increased continuously from 33.5 mg/dm^3 to 78 to 84 mg/dm^3. During the first part of 1979 it varied considerably from 30 to 100 mg/dm^3. In July and August it lowered to about 25 mg/dm^3 and remained unchanged until the end of 1979.

An increase in Na was observed in well B-2 between February 1978 and March 1979. From February until October 1978, the level rose from about 30 mg/dm^3 to 100 mg/dm^3. It remained at a level of 130 to 140 mg/dm^3 until April 1979, except in January and February when it dropped to 21 to 35 mg/dm^3. Between April and September Na content ranged from 70 to 90 mg/dm^3, then dropped to 20 to 40 mg/dm^3, i.e., to the levels found in other wells.

A continuous increase in Na (from 20 mg/dm^3 to a maximum of 160 to 170 mg/dm^3) was also observed in well B-1 between February 1978 and March 1979. However, in October 1978 and in January and February 1979, temporary decreases to 26 to 42 mg/dm^3 were recorded. Between April 1979 and September 1979, Na content was 70 to 110 mg/dm^3, then dropped to 20 to 40 mg/dm^3.

Water samples from well B-3 showed an increase in Na between 1978 (36 mg/dm^3) and March 1979 (135 to 150 mg/dm^3). Similar to wells B-1 and B-2, a temporary decrease (down to 28 to 36 mg/dm^3) was recorded in January and February 1979. In April 1979, the Na level rapidly decreased to 25 mg/dm^3 and then increased to a value of 122 mg/dm^3 in June. The level of Na again decreased to about 20 to 25 mg/dm^3 for the remainder of the investigation.

In other wells (B-9, B-10 and B-14) only singular increases in Na content (35 to 95 mg/dm^3) were noted but were probably due to extraneous factors.

In conclusion, the influence of the disposal operations on Na content in groundwater was significant beginning in 1978, 3 years after the disposal operations had begun, and remained an influence until September 1979. The polluted aquifer ranged 200-300 m north of the disposal site in the direction of groundwater flow. The maximum level of Na found in the polluted groundwater was 16 times greater than levels found in groundwater not in contact with the disposal site.

Potassium (K)

Potassium levels in laboratory leachates varied from 4.1 to 48.0 mg/dm^3, with an average of 26.3 mg/dm^3.

In 1974, before disposal operations began, K in groundwater ranged from 1.05 mg/dm^3 (well B-7) to 16.12 mg/dm^3 (well B-7). During the first two years of disposal operations (1975-76) K in groundwater was generally at the level observed in 1974 (between 1 and 5 mg/dm^3), except in October 1975 it reached 10 mg/dm^3 in well B-1.

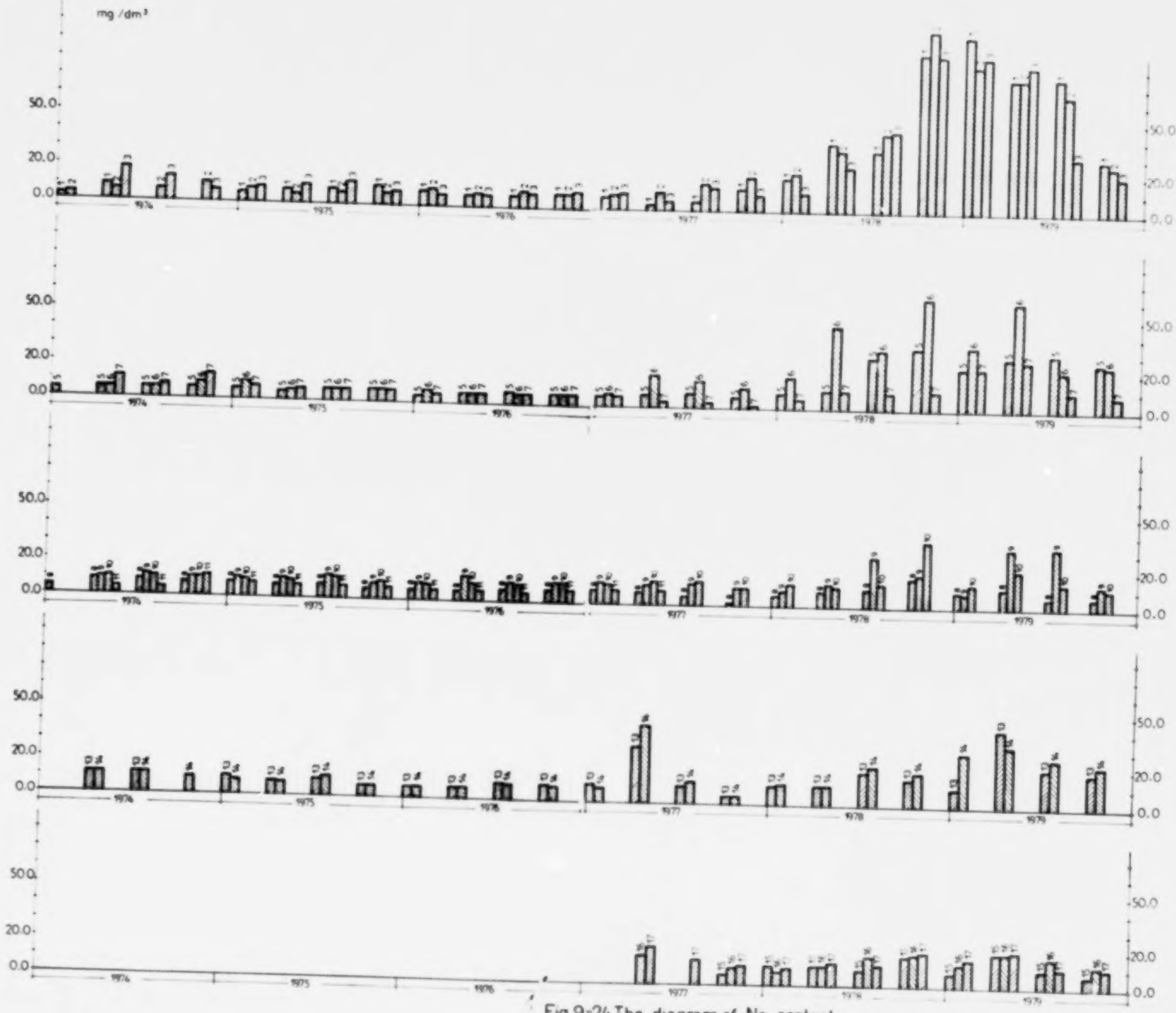


Fig.9-24.The diagram of Na content

Potassium content began to fluctuate during the third year of disposal operations. In January 1977, increased values were observed in wells B-6 and B-2; 8.5 mg/dm^3 of K were found in well B-6, while in other wells it did not exceed 3.0 mg/dm^3. Potassium levels continually increased and in July 1977 reached a maximum of 26.5 mg/dm^3, then dropped and remained between 10 and 15 mg/dm^3 for the duration of the investigation with some values of 2 to 4 mg/dm^3 reported.

During January 1977, in well B-2, K content was 4.1 mg/dm^3. Until August 1978, concentrations varied between 5 and 6.5 mg/dm^3. Between September 1978 and January 1979, it grew to a maximum of 8.5 mg/dm^3, then gradually decreased to 2.7 to 4.6 mg/dm^3 by the end of the reporting period.

In well B-1 between February and September 1977, increased K levels appeared infrequently, e.g. in February - 11.1 mg/dm^3, and in June, July and September - 4 to 5 mg/dm^3. From November 1979 until March 1979, the concentrations increased slightly from 5 to 6 mg/dm^3 to 8 to 9.5 mg/dm^3. Then it fell to 4.5 to 4.8 mg/dm^3, recorded at the end of 1979. In May a temporary increase to 10.5 mg/dm^3 was recorded.

Between March 1977 and February 1978, increased K levels in well B-3 were periodically reported. In March, June, October and December 1977, and in January 1978, concentrations reached 4.0 to 5.4 mg/dm^3. From March 1978 to the end of the reporting period K concentrations continued to increase. Unlike other wells, water samples from well B-3 indicated several peak potassium levels. The first occurred from March until July 1978 when it increased from 5.7 mg/dm^3 to 12.3 mg/dm^3 (maximum level recorded). K content dropped to 2.9 mg/dm^3, and in March 1979, it rose again (8.0 mg/dm^3) and dropped rapidly the next month to 2.6 mg/dm^3. Another instance of K increase in the groundwater was observed between May and November 1979 showing the values from 3.7 mg/dm^3 to 12.7 mg/dm^3. In December 1979, K content was reported at 2.9 mg/dm^3.

Temporary increases of K content (to about 8 mg/dm^3) were observed in wells B-9, B-13, B-14. Between 1977 and 1979, potassium content in other wells ranged from 2 to 4 mg/dm^3.

It can be concluded that the influence of disposal operations on K content in the groundwater appeared in January 1977 and continued at various degrees of intensity through the end of the investigation. Pollution from potassium was greatest north of the disposal pits 200-300 meters away in the direction of groundwater flow. However, the increase in potassium in the groundwater affected by the disposal site was much less than the sodium levels recorded.

Calcium (Ca)

The content of Ca in laboratory leachates varied from 5.2 to 355.9 mg/dm^3, averaging 75.9 mg/dm^3. Before disposal operations, Ca concentrations in groundwater varied from 5.5 mg/dm^3 (well B-8) to

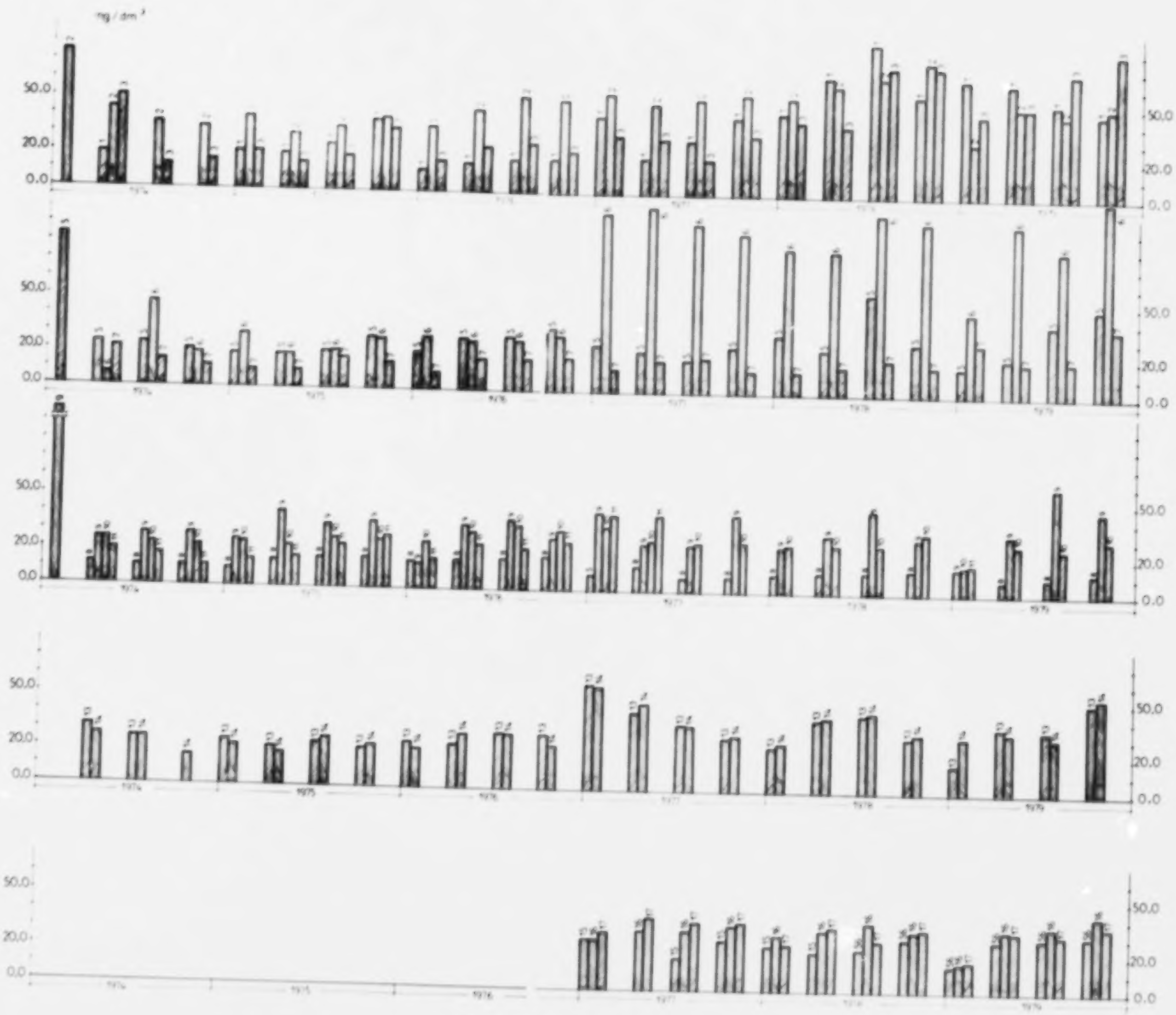


Fig.9-25 The diagram of K content

71.14 mg/dm^3 (well B-7). During the initial period of disposal operations, from November until December 1976, the Ca content in groundwater varied from 6 mg/dm^3 (well B-8) to 30 mg/dm^3 (well B-5), but most frequently it did not exceed 20 mg/dm^3. The first increases in Ca appeared at the end of 1976. In November and December 1976, higher values appeared in well B-6 (38.5 mg/dm^3) and in well B-2 (27.0 mg/dm^3). At the same time Ca content in the other wells was from 7.5 mg/dm^3 (well B-8) to 16.7 mg/dm^3 (well B-7).

Between the end of 1976 and June 1979, a continuous increase of Ca content was observed in well B-6. It periodically dropped but never below values observed in other wells. It varied from 20 to 52 mg/dm^3 with an average value of 24.3 mg/dm^3. In 1978, it ranged from 30 to 50 mg/dm^3, averaging 43.6 mg/dm^3. In the first six months of 1979, it was between 40 and 67 mg/dm^3 and its average value was 51.5 mg/dm^3. By July 1979, Ca content decreased to about 20 to 30 mg/dm^3, and for the remainder of the reporting period Ca concentrations averaged 40.5 mg/dm^3.

A continuous increase of Ca content was observed in well B-2 and in March 1979, reached a maximum of 63 to 69 mg/dm^3. In 1977, Ca content ranged from 20 to 39 mg/dm^3 (average value 27.6 mg/dm^3). In 1978, it was between 30 and 57 mg/dm^3, averaging 44.4 mg/dm^3. During the first three months of 1979, the concentrations varied between 26 and 69 mg/dm^3 (average 52.4 mg/dm^3). From April 1979 Ca content decreased to 24 to 44 mg/dm^3 and the average for the last nine months was 34.6 mg/dm^3.

Ca levels in well B-1 began to increase in October 1977 (21 mg/dm^3) and in March 1979 it reached 79 mg/dm^3. During the last three months of 1977, Ca content varied from 21 to 40 mg/dm^3 (average 32.5 mg/dm^3); in 1978, it was 30 to 50 mg/dm^3 (average 41.7 mg/dm^3); during the first three months of 1979 it varied from 29 to 79 mg/dm^3 (average 60 mg/dm^3). After April 1979, a gradual decrease of Ca content to about 30 mg/dm^3 was observed in the well.

A continuous increase of Ca content was also observed in well B-3. It began in October 1977 (20 mg/dm^3) and lasted until March 1979 (70 to 76 mg/dm^3). During the last three months of 1977 it remained between 20 and 33 mg/dm^3, averaging 25 mg/dm^3; in 1978 it averaged 36.2 mg/dm^3. During the first three months of 1979, it ranged from 30 to 76 mg/dm^3 (average 52.5 mg/dm^3). After April 1979, as in wells B-2 and B-1, a decrease of the Ca content was reported and generally varied between 30 and 40 mg/dm^3 (average 34.6 mg/dm^3).

Increased Ca content was observed in well B-5 between September 1978 and March 1979. During that time it ranged most frequently between 35 and 40 mg/dm^3. After September 1979, one small increase (20 to 35 mg/dm^3) occurred. Ca content in other wells varied from 8 to 33 mg/dm^3 between 1977 and 1979.

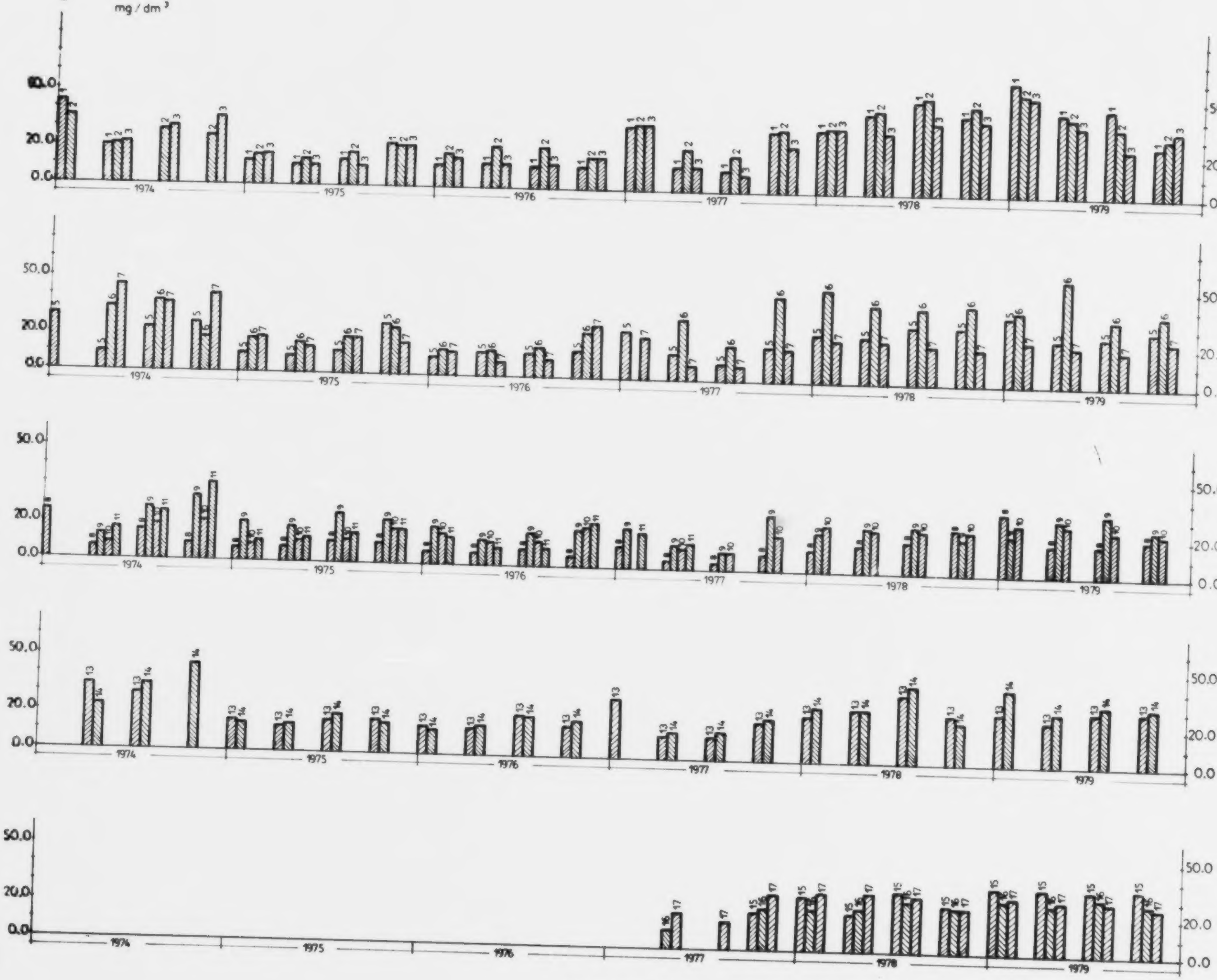


Fig. 9-26.The diagram of Ca content

It may be concluded that the content of Ca in the groundwater was influenced by disposal operations from 1977 through the end of the investigation (1979). The acquifer was slightly polluted 200-300 m north of the disposal pits, i.e., in the direction of groundwater flow. The pollution, however, was not very significant and the levels of Ca reported did not deteriorate the groundwater below drinking water standards.

Magnesium (Mg)

The content of magnesium in laboratory leachates varied considerably, ranging between 0.42 and 21.85 mg/dm^3 and averaging 7.3 mg/dm^3. Mg content in the groundwater before disposal operations was from 2.12 mg/dm^3 (well B-3) to 28.06 mg/dm^3. In the period 1975-1976 Mg levels in the groundwater were considerably lower than values observed in 1974, and varied between 3 and 7 mg/dm^3. Temporary increases were observed simultaneously in all wells during that period.

Beginning in 1977, Mg content gradually began to change. In January 1977, an increase (9.35 mg/dm^3) was observed in well B-6, while in other wells it generally did not exceed 7 mg/dm^3. Throughout 1977 until August 1978, Mg levels remained between 9.0 and 13.5 mg/dm^3; however, temporary decreases to 4 to 6 mg/dm^3 were noted. The content of Mg gradually increased from an initial value of 6.0 mg/dm^3 to 15.8 mg/dm^3 observed in January 1979. Also in January the content of Mg in all wells located beyond the disposal zone increased considerably (most frequently about 10 mg/dm^3), and remained at that level until the end of 1979. Between February 1979 and the end of the year Mg content in well B-6 varied between 8 and 13 mg/dm^3.

In June 1977, wells B-1, B-2, B-3 and B-17 also began to show increased Mg content. Increases in Mg in well B-1 occurred in two cycles. The first cycle lasted from June 1977 until September 1978 increasing from 7.0 mg/dm^3 to 19.6 mg/dm^3. Then it dropped to 11.0 mg/dm^3 for a short time. The second cycle comprised the period between October 1978 and January 1979. During this time, Mg content increased gradually to a maximum value of 26.0 mg/dm^3. It gradually lowered, and in April 1979, it was about 18 mg/dm^3. Levels at the end of 1979 were from 8 to 10 mg/dm^3, also the levels found in wells located beyond the disposal zone.

Mg content in well B-2 increased in a similar manner. In the first cycle (June 1977 to September 1978) Mg content gradually increased from 8.2 mg/dm^3 to 20.0 mg/dm^3. The second cycle occurred from October 1978 to January 1979. During that time Mg content increased to 21.6 mg/dm^3. In February 1979, the level began to drop and by the end of the year, it usually ranged from 10 to 16 mg/dm^3.

Increased content of Mg occurred in well B-3 from June 1977 to January 1979. During that period the levels varied between 7 and 15 mg/dm^3, and only in December 1978 and January 1979 it did reach 17 and 28 mg/dm^3, respectively. Then it dropped first to 13 mg/dm^3 and then in June 1979 to about 8-12 mg/dm^3, the level observed in other wells.

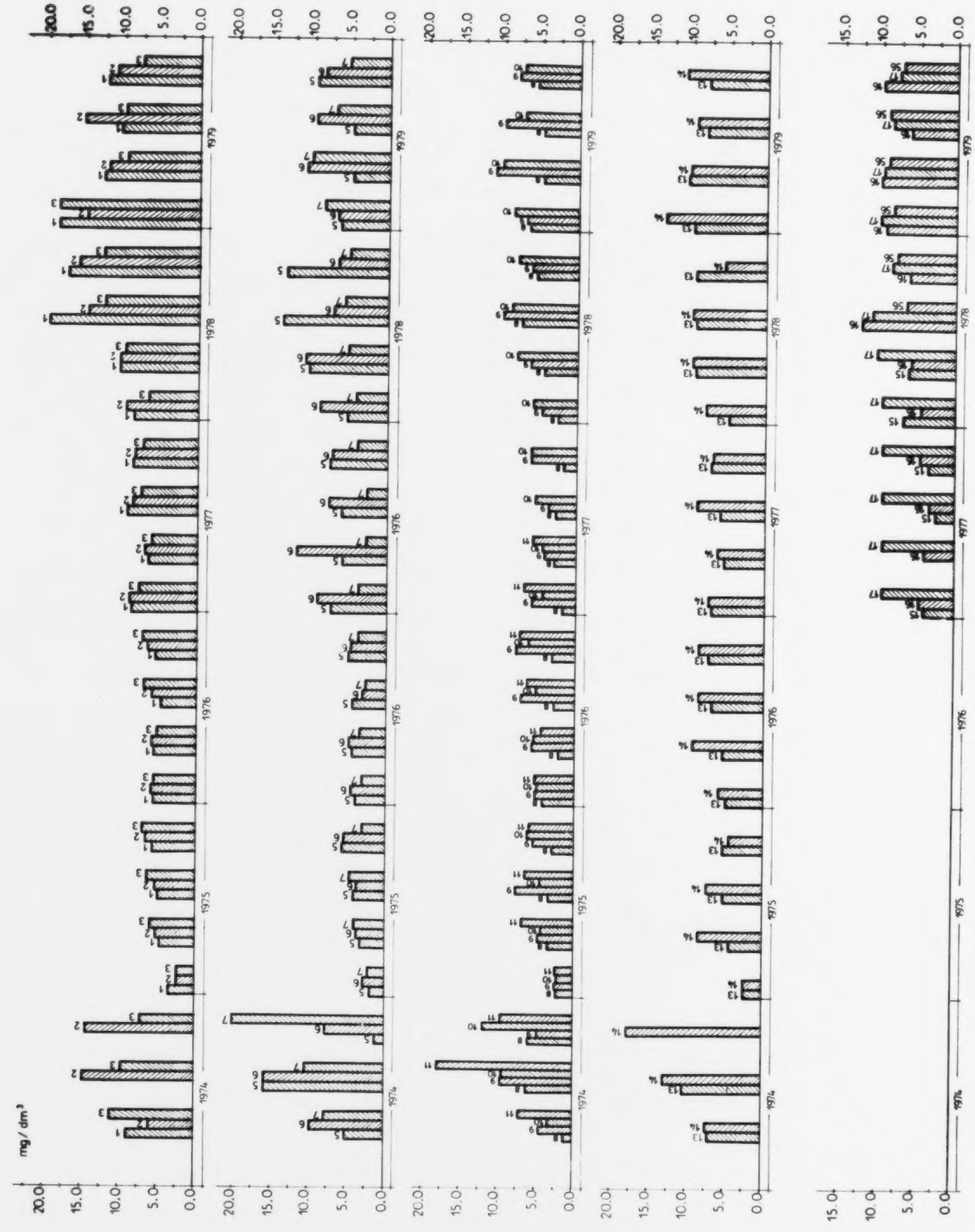


Fig. 9-27. The diagram of Mg content

In well B-17, increased content of Mg (9 to 13 mg/dm^3) was observed only from June 1977 until August 1978. In this well, Mg remained stable, although periodic variations occurred.

In well B-5 the content of Mg gradually increased from April to July 1978, rising from 8.8 mg/dm^3 to 23.6 mg/dm^3. Then it decreased and, except for a temporary increase to 19 mg/dm^3 (April 1979) it remained at a level of 8 to 10 mg/dm^3.

Periodically high values of Mg were recorded in well B-13 (15.4 and 14.4 mg/dm^3 in April and October 1978) and in well B-10 (13.2 mg/dm^3 in November 1978).

The effect of the wastes on Mg content in the groundwater began in 1977 and remained considerable until the beginning of 1979. In the first six months of 1979, the content became less significant. It should be emphasized that after January 1979 the content of Mg in the groundwater samples from all tested wells increased considerably as compared to values observed during the initial period of disposal and ranged from 8 to 12 mg/dm^3 in the wells located beyond the disposal influence zone. The polluted area included the aquifer north of the pits, 200-300 m in the direction of groundwater flow.

Manganese (Mn)

The content of manganese in laboratory leachates varied from 0.035 to 2.995 mg/dm^3, an average of 0.729 mg/dm^3. During the initial period of disposal operations until June 1975, Mn content in groundwater ranged from 0.05 mg/dm^3 (wells B-9, B-10) to 0.387 mg/dm^3 (wells B-11, B-12). From that time some changes in Mn content occurred.

From July 1975 to September 1977, higher concentrations of Mn were found in well B-1 where they varied from 0.5 to 0.8 mg/dm^3. In November 1975 and April 1977, it reached 1.2 mg/dm^3. In other wells the Mn content did not exceed 0.3 mg/dm^3. Then in April 1978, the content increased to 1.35 mg/dm^3, and in October 1978 to 0.60 mg/dm^3.

Higher values of Mn occurred also in well B-3 in December 1975 and in February 1976 (0.45 mg/dm^3), in August 1976 (1.46 mg/dm^3), in April 1977 (0.70 mg/dm^3, and in April 1978 (1.55 mg/dm^3). Between these peaks Mn content varied between 0.10 to 0.20 mg/dm^3. A continuous increase of Mn content (0.35 to 0.50 mg/dm^3) was observed from August 1978 until May 1979.

An increased level of Mn was periodically reported in well B-2. A very high level (1.70 mg/dm^3) was observed only once, in April 1978, while lower values (0.40 - 0.50 mg/dm^3) were noticed in September and October 1979.

In well B-5 increased levels of Mn were observed in September, 1975, November 1976 and May 1977 ranging from 0.40 to 0.80 mg/dm^3.

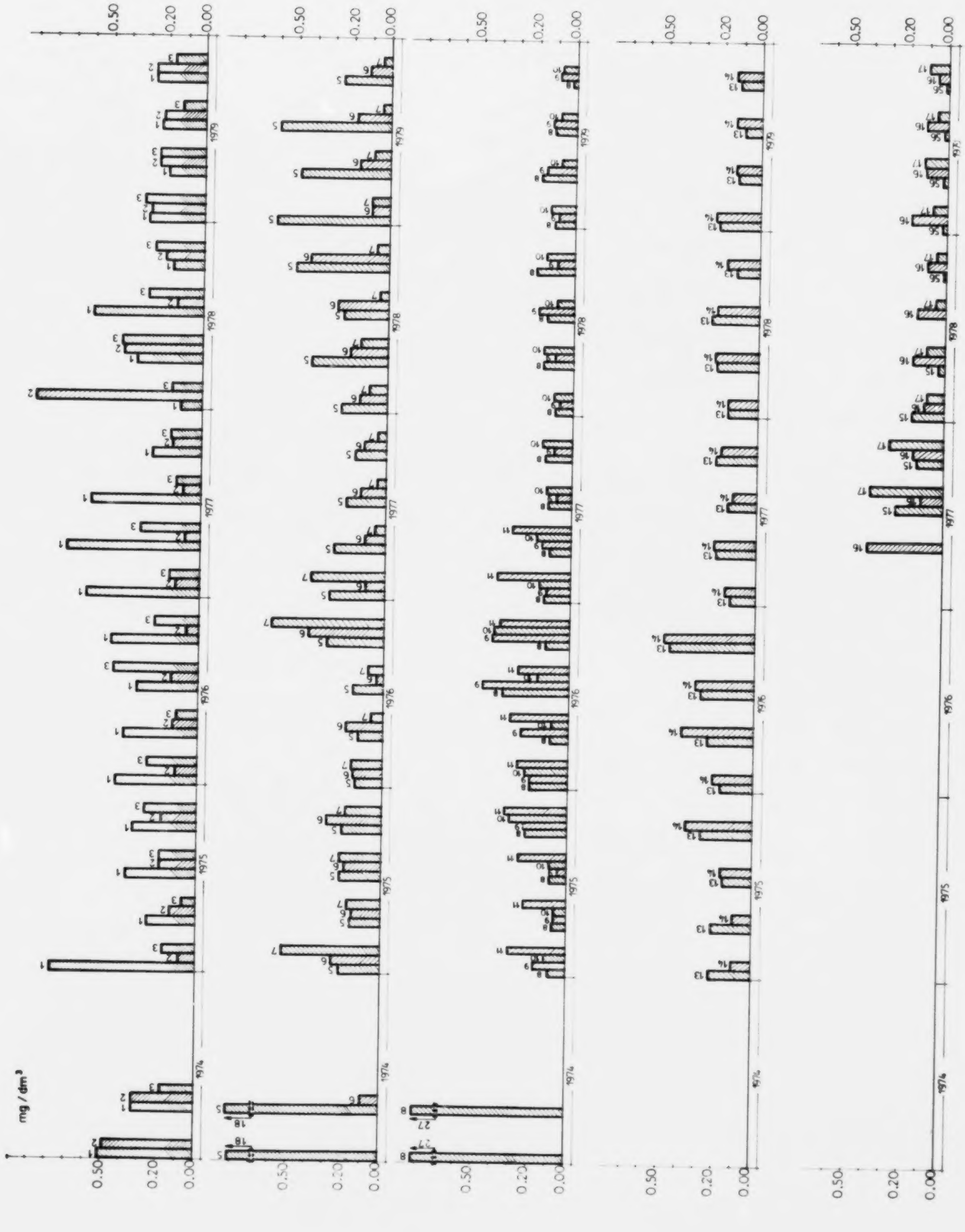


Fig. 9-28. The diagram of Mn content

At other times, Mn content ranged from 0.20 to 0.30 mg/dm^3. From April 1978 until October 1979 a steady increase in Mn (0.40 - 0.99 mg/dm^3) was observed.

Well B-6 showed higher Mn content occasionally in December 1976 (0.81 mg/dm^3) and from September until December 1978 (0.38 to 0.50 mg/dm^3).

It may be concluded that the influence of disposal on Mn content in the groundwater was different from its influence on other components. Pollution from Mn was not continuous and appeared at various times, and generally earlier than other pollutants. Further it did not necessarily appear in the same wells as other pollutants, but mostly in wells under the influence of disposal. The origin of this phenomenon is not readily understandable and did not correspond to the laboratory leachate tests.

The disposal operations affected the aquifer 200-300 m north of the disposals.

Iron (Total Fe)

The content of total iron in laboratory leachates varied from 0.11 to 75.8 mg/dm^3, averaging 24.6 mg/dm^3. The content of this component in groundwater prior to disposal operations (1974) varied from well to well and fluctuated periodically. It ranged from 0.0 mg/dm^3 (wells B-6, B-7, B-8 and others) to 10 to 13 mg/dm^3 (wells B-1, B-2). During the initial period of disposal (during 1975) Fe content remained variable. Its concentrations were similar to concentrations observed in 1974 and varied from 0.1 mg/dm^3 (wells B-3, B-5, B-6 and others) to 13 mg/dm^3 (wells B-1, B-2, B-5, B-13 and others). In 1976 the Fe content in groundwater changed significantly.

The increase of Fe in well B-1 was irregular. In January 1976, it was 12.3 mg/dm^3 while in January through March 1977, it reached a maximum of 28 mg/dm^3. From then until the end of October 1978 Fe gradually decreased to about 0.1 mg/dm^3, also observed in other wells. Then during November 1978 it rapidly increased to 12 mg/dm^3 and remained at that level until the end of March 1979. Until the end of the reporting period, Fe content ranged from 1.5 to 2.0 mg/dm^3.

In well B-2 an increased Fe content was observed from the beginning of 1976 until the end of 1979. In 1976, 1977 and the first six months of 1978, Fe content most often ranged between 1.5 and 2.0 mg/dm^3. Starting in July 1978 until March 1979, it gradually increased from 8.0 mg/dm^3 (August 1978) to a maximum of 17.0 mg/dm^3. It dropped to 0.5 mg/dm^3, except in 1979 when it reached 6.0 mg/dm^3.

A gradual increase in Fe content was observed in well B-5 from September 1978 until March 1979. During that period it rose from 1.65 mg/dm^3 to 12.2 mg/dm^3. Then it dropped below 1.0 mg/dm^3; however, once in December 1979 a level of 2.5 mg/dm^3 was observed.

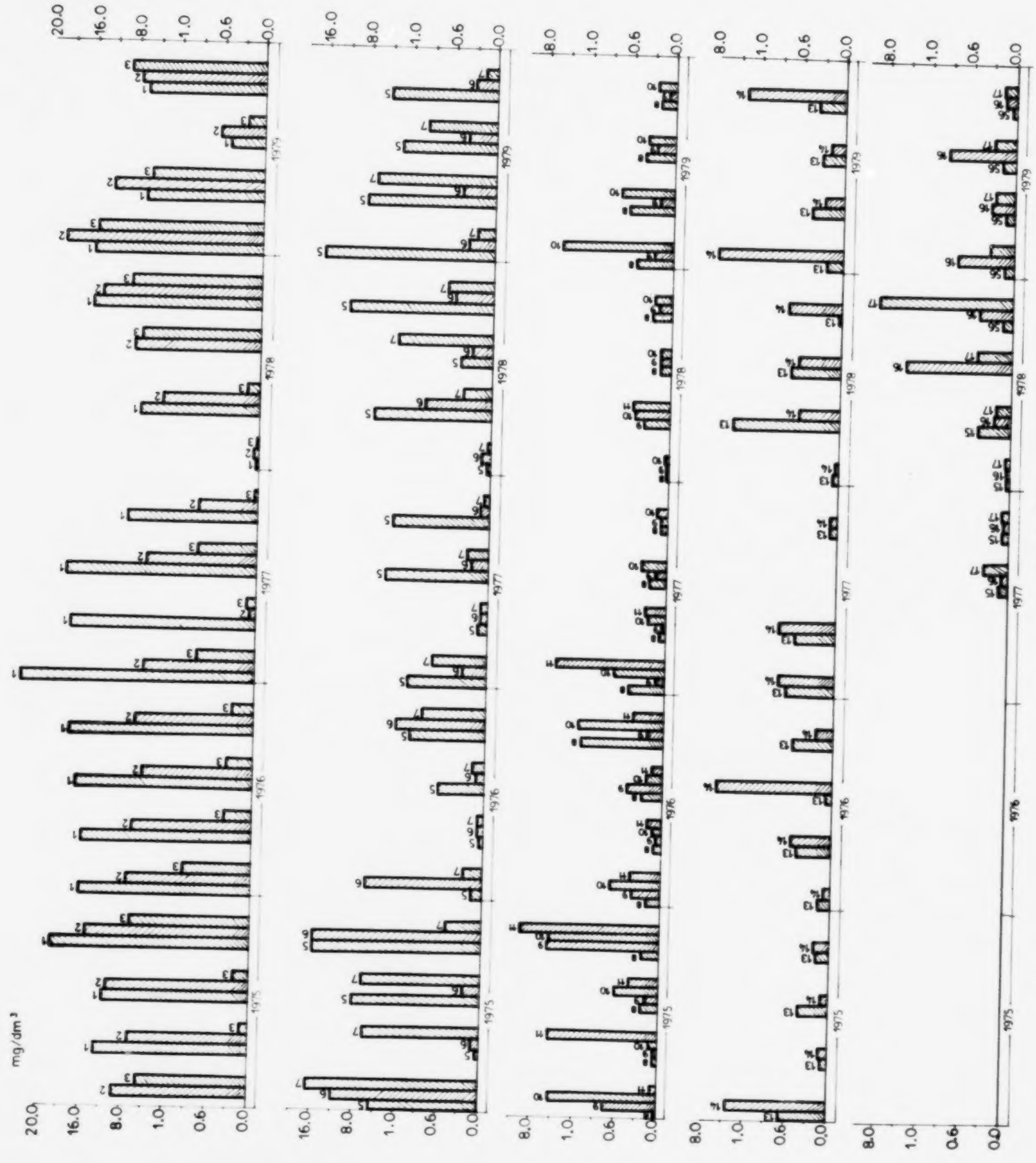


Fig. 9-29. The diagram of Fe content

In well B-3 Fe content was higher from August 1978 to May 1979; however, the maximum (9-11 mg/dm^3) was observed between December 1978 and March 1979. Additional episodes of increased concentrations of Fe occurred in April 1978 in well B-6 (1.21 mg/dm^3) and well B-13 (1.71 mg/dm^3), and from March to May and in December 1979 in well B-14 (1.0 - 3.8 mg/dm^3). In other wells total Fe content between 1977 and 1979 varied between 0.1 and 0.4 mg/dm^3.

It may be concluded that disposal effected an increase in the content of total Fe in groundwater north of the disposal site. The polluted area was smaller than the area affected by the previously discussed pollutants (100-150 m). Pollution of the groundwater by Fe was slightly different as compared to other components. It appeared earlier, at the beginning of 1976 (after the first year of disposal operations) and remained evident until the end of the investigation. Maximum Fe levels appeared earlier (at the beginning of 1977) while maximum values of other pollutants appeared as late as in March 1979. No continuous increase of Fe content in well B-6 was observed, however this phenomenon was characteristic of other components.

This different behavior of Fe is difficult to explain and without apparent reason.

Ammonium (NH_4)

The content of NH_4 in laboratory leachates varied from 0.32 to 4.46 mg/dm^3, averaging 1.73 mg/dm^3. During disposal operations its content in groundwater ranged most frequently (except in November 1979) from 0.1 to 0.5 mg/dm^3 except in wells B-1, B-6 and B-17 where considerable increases of this ion appeared periodically. Higher NH_4 levels were noticed in well B-1 in 1975 and in wells B-6 and B-17 after September 1977.

In 1975 higher levels of NH_4 in well B-1 (1.0 to 1.6 mg/dm^3) appeared in two cycles. Each time NH_4 concentration rose then dropped to values observed in other wells. The first increase was noticed early in 1976 and was observed until May 1977 (concentrations 0.7 - 2.0 mg/dm^3). Then NH_4 content decreased to levels observed in other wells, i.e., 0.1 - 0.4 mg/dm^3, and lasted until March 1979. The next period of increased NH_4 content began in May 1979, reaching its maximum of 6.8 mg/dm^3 and remained at a level of about 2.5 mg/dm^3 through the end of the observations.

The first indications of NH_4 increase in well B-6 appeared in September 1977 when its concentration was 1.14 mg/dm^3. In August 1978, it was 1.60 mg/dm^3. In December 1978 NH_4 content was 4.54 mg/dm^3 and grew to a maximum of 8.90 mg/dm^3 in May 1979. Then it decreased slightly and remained at a level of 6-8 mg/dm^3 through the end of 1979.

NH_4 content in well B-17 increased from 1.0 to 1.3 mg/dm^3 during the period: September 1977 to February 1978 and to 1.9 mg/dm^3 in December 1979. Higher NH_4 levels were observed in well B-14 (1.0 to

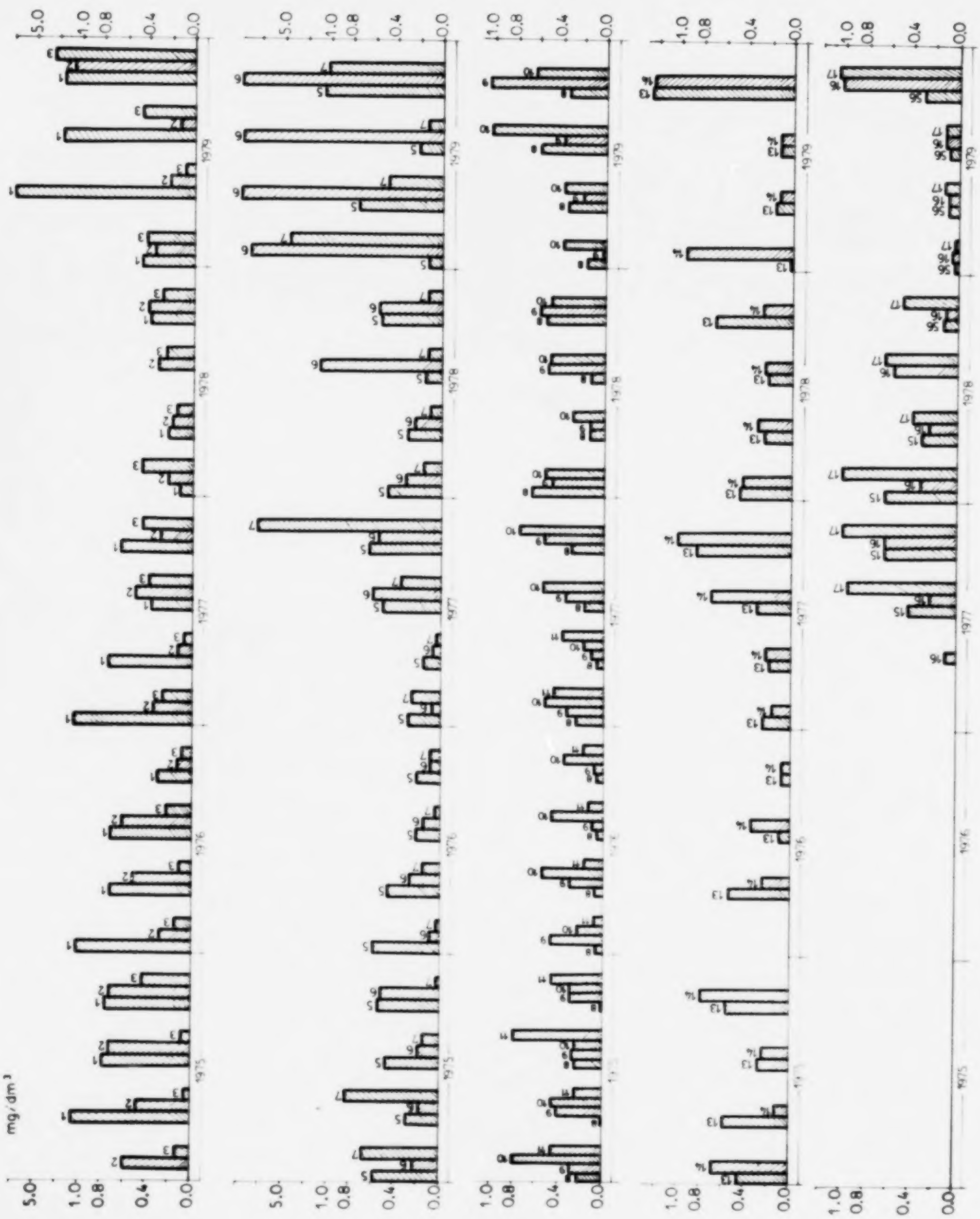


Fig. 9-30.The diagram of NH_4 content

1.2 mg/dm^3) in September and November 1977, in well B-10 (1.2 mg/dm^3) in August 1979, and in all wells in November 1979.

On the basis of the above it may be stated that the increase in NH_4 in wells B-1, B-6 and B-17 were caused by the disposal operations. All these three wells were in direct downstream flow of the pollutants. Pollution of groundwater from NH_4 was not continuous, but appeared periodically with varying intensity. The highest pollution level recorded occurred during the first six months of 1979 later than other pollutants (the fourth year of disposal operations). The disposal operations affected the aquifer for a distance of about 100 m north of the site, the smallest area influenced by a particular pollutant in this discussion.

Phosphate (PO_4)

The content of phosphates in laboratory leachates ranged from 0.036 mg/dm^3 to 3.140 mg/dm^3, and its average was 0.522 mg/dm^3. During the period January 1975 to June 1976 the content of PO_4 in groundwater in all tested wells varied from 0.002 mg/dm^3 to 0.09 mg/dm^3. Only in September 1975 did the value in all tested wells increase to 0.01 - 0.06 mg/dm^3. From then until the end of the observations PO_4 concentrations remained between 0.03 and 0.09 mg/dm^3; however in April 1978 it was about 0.09 mg/dm^3 in the majority of wells.

It was found that the irregularity of PO_4 distribution in tested wells did not indicate any influence of the disposal site on pollution in the groundwater. However, the potential of pollution exists which is indicated by the greater content of PO_4 in laboratory leachates.

Cyanide (CN)

The content of CN in laboratory leachates varied from 0.003 to 0.066 mg/dm^3 (average 0.025 mg/dm^3).

During disposal operations the content of CN in groundwater ranged mostly from 0.002 to 0.006 mg/dm^3 except for wells B-1, B-2, B-5, B-7, B-9, B-10, B-15, B-17 in which higher values (0.010 to 0.025 mg/dm^3) were occasionally observed. Increased levels of CN were observed in well B-1 in November 1976 and April 1978; in well B-6 in August 1976 and December 1978; in well B-10 in June and August 1976 and in well B-17 in February and April 1978. Higher CN values were observed once in wells B-7 and B-9 in August 1976; in well B-5 in November 1976; in well B-15 in February 1978; in wells B-13 and B-14 in April 1978; and in wells B-2 and B-3 in December 1978. Additionally, between March and May 1979 all the tested wells showed higher concentrations of CN (0.10 - 0.20 mg/dm^3).

Distribution of CN in groundwater during disposal operations indicated that the impact of disposal operations on the pollution of groundwater by this ion is doubtful. Observations at wells B-7, B-9 and B-10 located outside the disposal influence zone, suggest that temporary increases of CN content might come from other sources. Also, the poten-

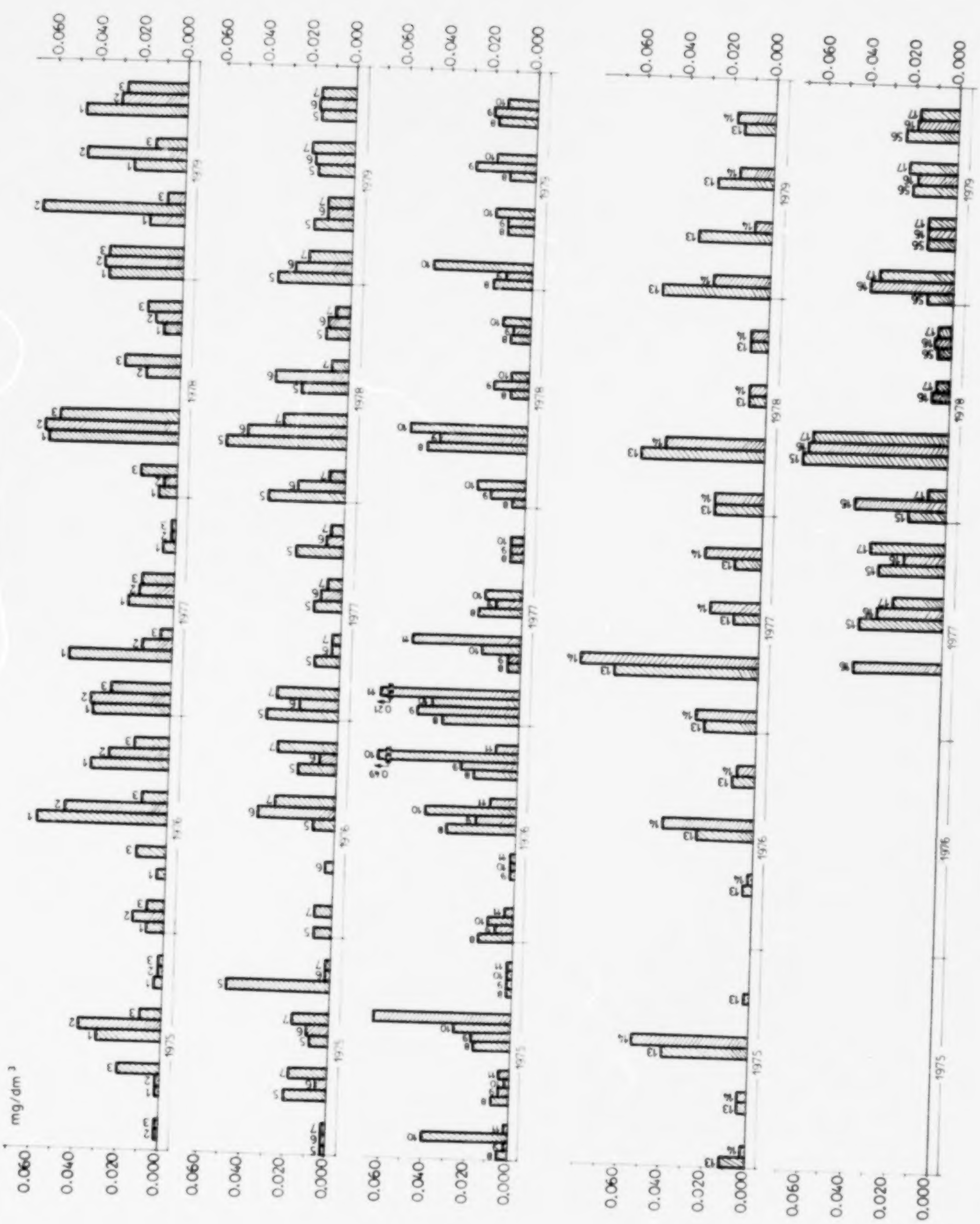


Fig.9-31. The diagram of PO₄ content

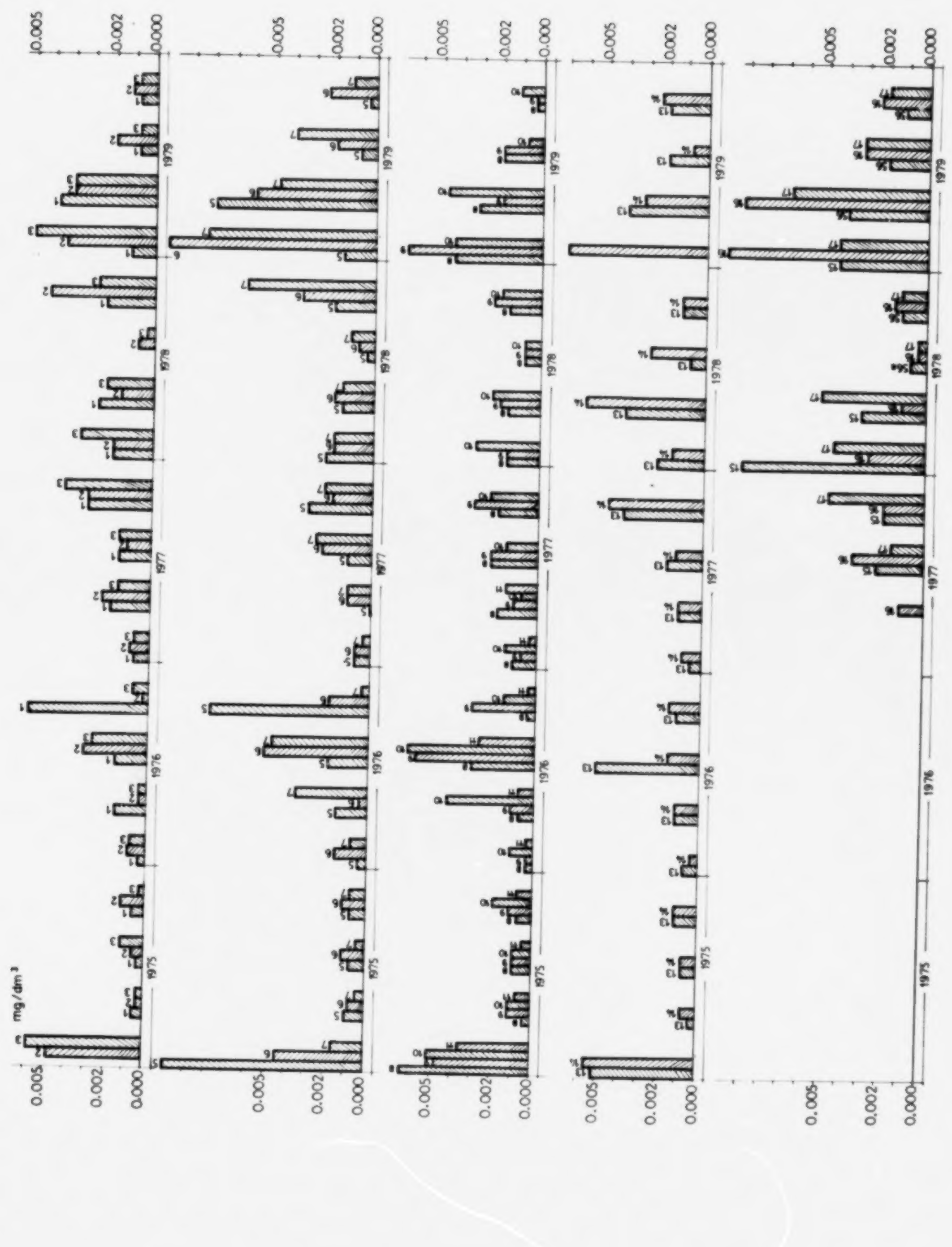


Fig.9-32.The diagram of CN content

tial of pollution is not clear because the concentration of CN in laboratory leachates varied considerably.

Phenols

The content of phenols in laboratory leachates varied from 0.008 to 0.088 mg/dm^3, averaging 0.0282 mg/dm^3. During disposal operations phenol content in groundwater ranged from 0.002 to 0.007 mg/dm^3 except in monitoring wells B-1, B-2, B-3, B-6, B-7, B-11, B-14 and B-16 where higher concentrations of phenols (0.010 - 0.014 mg/dm^3) were observed.

In 1975 higher values appeared only in well B-3; in 1976, high values were found in B-7 and B-11. During the next two years (1977 to 1978) phenols content did not increase in any of the monitored wells. As late as November 1979, higher concentration of phenols appeared in five wells (B-1, B-2, B-6, B-14, B-16).

Distribution of phenols in groundwater, observed during disposal operations, does not clearly indicate the impact of the disposal operations. Temporary increases in phenols levels might be due to other factors.

This conclusion is based on the that higher values were also observed in the monitoring wells situated outside the direct disposal zone (B-7, B-11 and B-14), and that increased levels of phenols were observed in the final phase of disposal operations, i.e. in November 1979, while the contents of other components at the same time dropped significantly.

Aluminium (Al)

The content of Al in laboratory leachates varied from 0.175 to 38.500 mg/dm^3, averaging 11.71 mg/dm^3. In 1974 before disposal operations began Al content in groundwater ranged from 0.0 mg/dm^3 (wells B-8, B-10, B-13 and others) to 0.376 mg/dm^3 (well B-9). During the initial period of refuse storage (1975 and the first six months of 1976) distribution of Al content in groundwater did not change as compared to levels observed in 1974. The concentrations were still between 0.05 mg/dm^3 (wells B-3, B-2 and others) and 0.35 mg/dm^3 (well B-1).

From August 1976 to August 1979 Al values in most wells, except B-1, B-2, B-3, B-5 B-6 and B-17, still did not exceed 0.1 mg/dm^3. Most frequently it was about 0.05 mg/dm^3; however, in April 1978 and March 1979 the concentrations in all wells were from 0.20 mg/dm^3 (well B-7) to 0.70 mg/dm^3 (well B-1), and from 0.22 mg/dm^3 (well B-1) to 0.42 mg/dm^3 (well B-9), respectively. By the end of 1979 (November and December) Al content in all wells was higher than 0.1 mg/dm^3 and most frequently varied from 0.15 to 0.20 mg/dm^3.

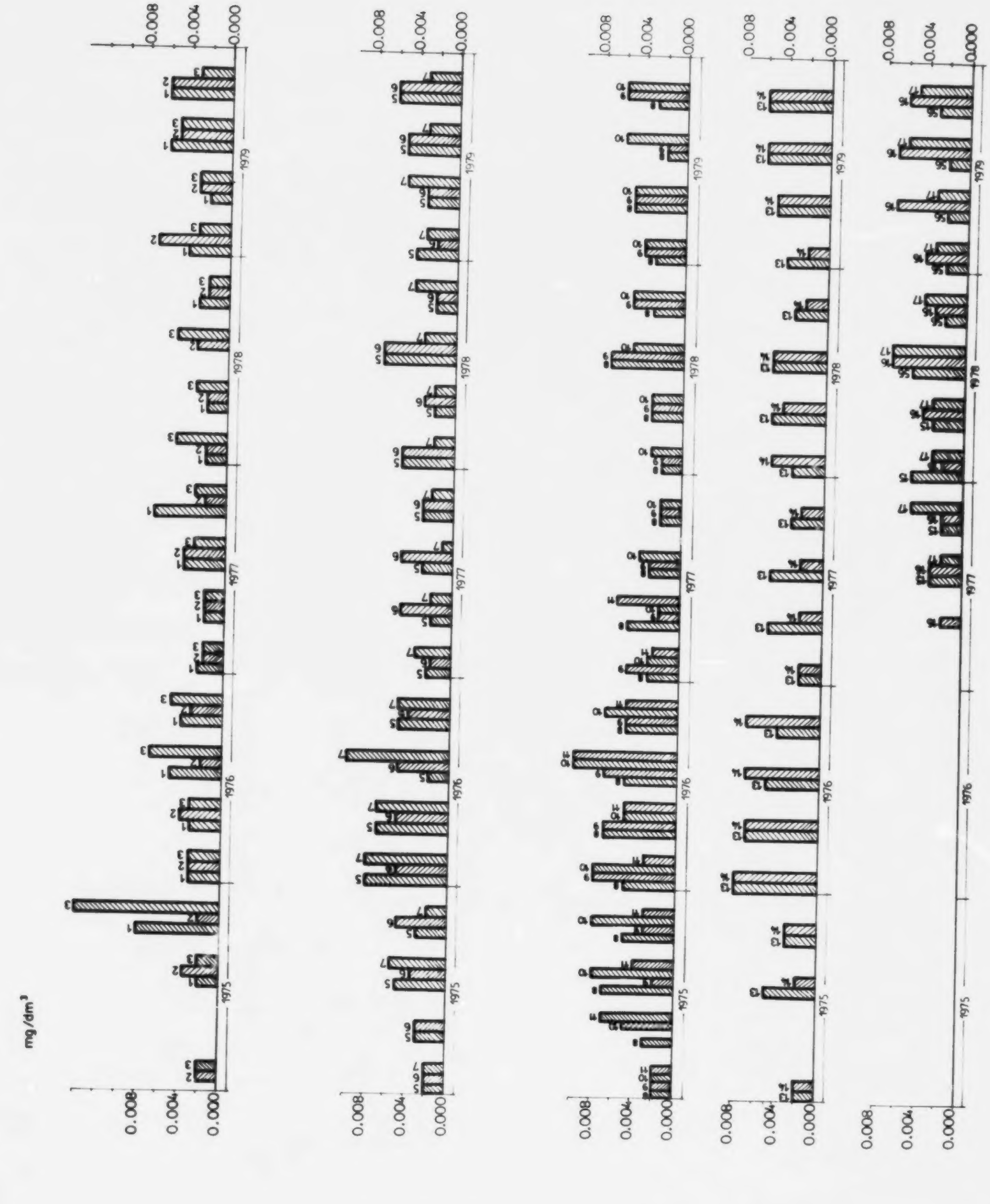


Fig.9-33.The diagram of phenols content

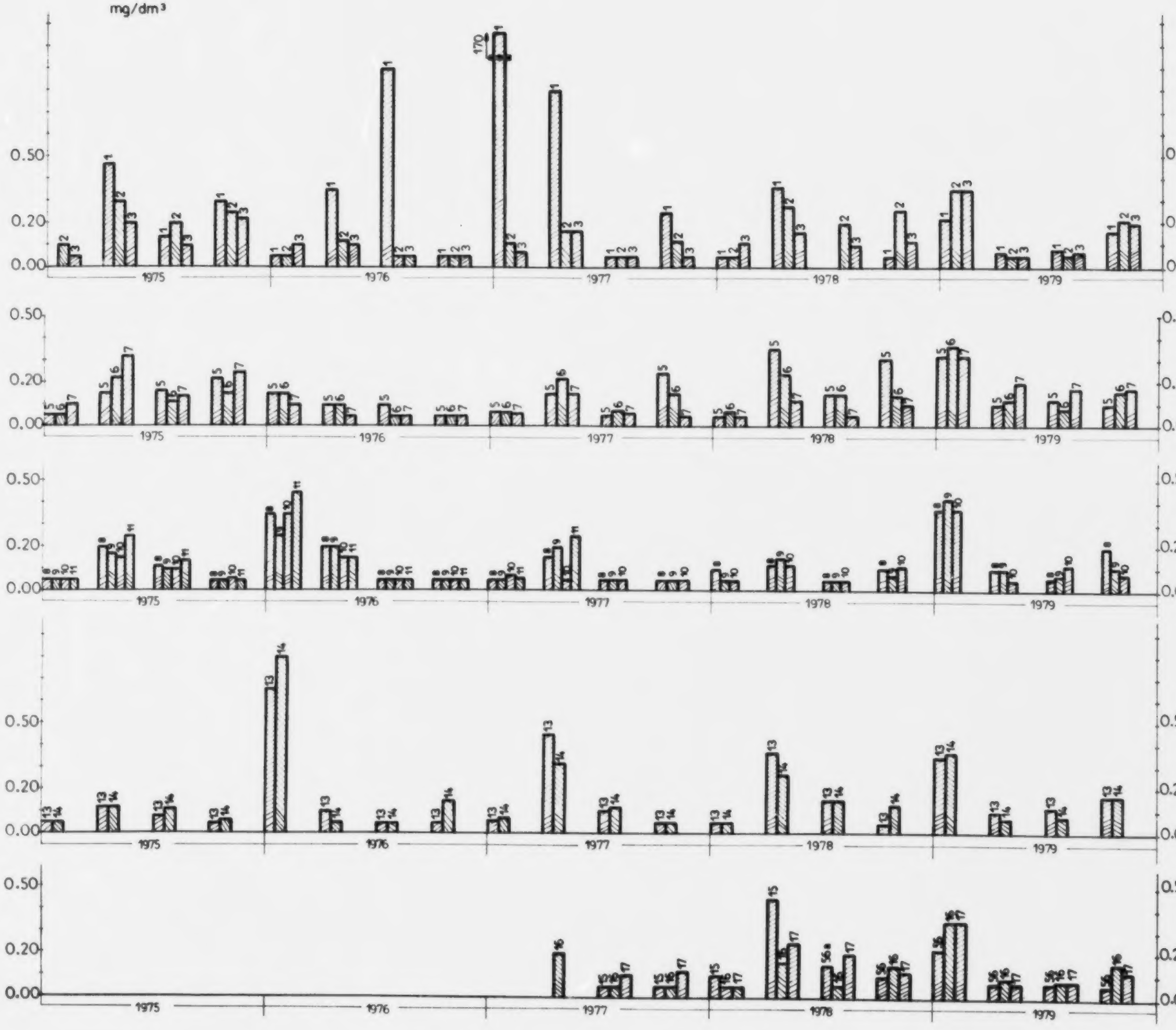


Fig.9-34.The diagram of Al content

Periodically higher levels of Al were observed between August 1976 and August 1979 in the wells under disposal influence, i.e. in wells B-1, B-2, B-3, B-5, B-6, B-17; however, in each well the increases appeared at different times and with different intensities. First, well B-1 showed higher Al content in August 1976 (0.9 mg/dm^3), and again (0.8 - 2.6 mg/dm^3) in January through May 1977. The maximum content noted during that period was 2.6 mg/dm^3. Another high Al level (to 0.25 mg/dm^3) was in observed in this well in November 1977.

Higher Al levels (0.15 to 0.17 mg/dm^3) were found in well B-2 in March through May 1977 and in November 1977 (0.12 mg/dm^3). Then from June until October 1978, the content again gradually increased to a maximum level of 0.47 mg/dm^3.

Higher concentrations of Al were observed also in well B-3 in May 1977 (0.17 mg/dm^3), in February through April 1978 (maximum 0.12 mg/dm^3 to 0.25 mg/dm^3) and in August 1978 (0.10 mg/dm^3).

In well B-5 increased levels of Al were observed in May 1977 (0.15 mg/dm^3), November 1977 (0.25 mg/dm^3) and from June through December 1978 varying from 0.17 mg/dm^3 to a maximum of 0.40 mg/dm^3, found in October.

In well B-6 increased Al content appeared for short periods of time. Higher values (0.11 to 0.22 mg/dm^3) were periodically observed in May and November 1977, and in August and December 1978. Increased Al content was observed in well B-17 in September 1977 (0.12 mg/dm^3) and from June through August 1978 (0.20 to 0.25 mg/dm^3).

It may be concluded that periodically higher Al content in groundwater was due to disposal operations. This is confirmed by the fact that increased Al levels were found in wells situated in the direction of groundwater flow. The aquifer was polluted 200 to 300 m north of the disposal site. The highest concentrations of Al were found in the closest wells situated 50 to 150 m from the disposal pits.

Zinc (Zn)

The content of Zn in laboratory leachates varied from 0.360 to 3.085 mg/dm^3, and its average was 0.883 mg/dm^3. The content of Zn in groundwater during disposal operations showed periodic changes, the difference being many times higher or lower than levels found prior to disposal. In 1975, Zn concentrations ranged from 0.020 mg/dm^3 (well B-7) to 0.07 mg/dm^3 (well B-3). Only in September were concentrations in all wells from 0.10 to 0.24 mg/dm^3. In July Zn levels reached 0.325 mg/dm^3 in well B-6.

In 1976, especially during the first six months, Zn content in all wells was considerably higher than in 1975 and varied from 0.5 to 4.2 mg/dm^3. Values higher than 0.5 mg/dm^3 were found in wells B-1 (4.20 mg/dm^3), B-6 (1.40 to 3.75 mg/dm^3), and in B-2, B-12, B-13, B-14 (0.8 to 1.2 mg/dm^3). During the second half of 1976, and until the end of 1979, Zn content occasionally fluctuated between 0.05 to 0.10 mg/dm^3 and 0.15 to 0.20 mg/dm^3. Water samples from the remaining wells showed periodic increases. In well B-1 a higher content of Zn was noted in November 1977 and in June 1978 (0.169 and 0.150 mg/dm^3), while in the remaining wells the content did not exceed 0.05 mg/dm^3. In March 1979 the maximum value in well B-1 was 0.53 mg/dm^3 and in November 1979 - 0.26 mg/dm^3.

In well B-2 higher concentrations were observed in November 1977 (0.127 mg/dm^3), in March 1979 (0.165 mg/dm^3) and in November 1979 (0.470 mg/dm^3). In well B-3 increases appeared in January and November 1977 (0.285 mg/dm^3 and 0.175 mg/dm^3, respectively). In June 1978, it was 0.11 mg/dm^3 and in March 1979, 0.147 mg/dm^3.

In well B-5 higher concentrations of Zn (4.0 mg/dm^3) were observed in June 1978.

Slightly increased Zn content (0.21 to 0.23 mg/dm^3) was observed in well B-6 in September 1977 and April 1978.

In well B-8, the content increased in February and June 1978 to 0.19 and 0.16 mg/dm^3. In well B-9, increased content of Zn appeared twice: in February 1978 (0.28 mg/dm^3) and November 1979 (0.420 mg/dm^3).

In well B-13 Zn content rose to 0.5 mg/dm^3, observed in November 1979. In well B-14 Zn content increased in May and November 1979, the levels being 0.46 and 0.80 mg/dm^3, respectively.

In wells B-15 and B-17 higher content of Zn was observed only once, in April 1978 (0.325 mg/dm^3) in well B-15 and in well B-17 in December 1978 (0.525 mg/dm^3).

Conclusions are that the distribution of Zn in groundwater does not indicate that the disposal operations were clearly responsible for the pollution. Increased levels of Zn were observed in wells situated in the direction of the groundwater flow (within the disposal's area of influence) but were also found in other directions. However, the increases appear more frequently and at higher levels in wells within the disposal zone, which indicates the influence as quite possible.

Copper (Cu)

The content of Cu in laboratory leachates varied from 0.019 to 0.925 mg/dm^3 and its average value was 0.197 mg/dm^3. During disposal operations Cu content in groundwater normally ranged from 0.003 to 0.017 mg/dm^3. Only in wells B-1, B-3, B-5, B-6, B-7 and B-10 were periodic or singular increases in Cu observed that were higher than those in other wells.

The most significant and longest lasting increases in Cu levels were found in wells B-5 and B-3, while in wells B-1, B-6, B-7 and B-10 the increases were lower and temporary.

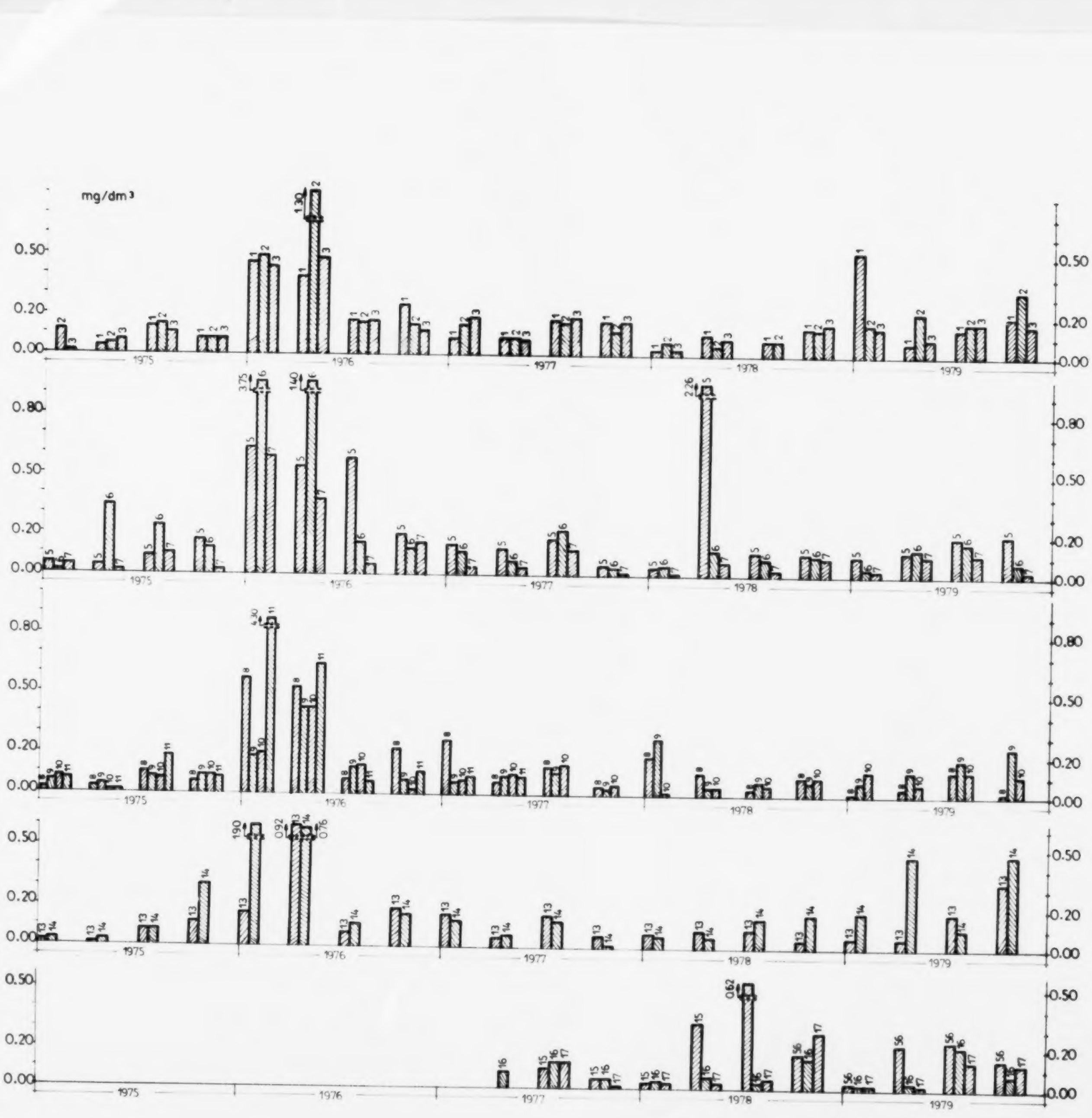


Fig.9-35. The diagram of Zn content

In well B-5 increased Cu content (0.650 mg/dm^3) appeared in August 1976 and remained at this level until January 1977, then dropped until April 1978, however they remained higher than normal (0.180 to 0.270 mg/dm^3).

In well B-3 increased Cu content (0.210 mg/dm^3 to 0.420 mg/dm^3) appeared in August 1976 and remained high until January 1977.

In well B-1 increased Cu content (0.165 mg/dm^3) was observed in March 1976 and in well B-7 higher Cu values (0.440 mg/dm^3) appeared in November 1977. During April 1978 higher Cu concentrations (0.150 to 0.170 mg/dm^3) were noticed in wells B-6, B-7 and B-10. At the same time levels in other wells never exceeded 0.03 mg/dm^3.

Some increased levels of copper were found at the start of 1976 and 1977 in the wells outside of the disposal influence (B-13 and B-14).

It may be concluded that increased Cu content in groundwater was very probably caused by the disposal operations. This was confirmed by increased concentrations of Cu appearing mostly in wells located in the direction of groundwater flow, north of the disposal site. The most significant pollution was measured 100 to 150 m from the disposal pits.

Lead (Pb)

The content of Pb in laboratory leachates varied from 0.034 to 0.271 mg/dm^3, and its average value was 0.196 mg/dm^3. The content of Pb in groundwater during disposal operations ranged from 0.010 mg/dm^3 to 0.060 mg/dm^3. Only between June and December 1978 was it lower (0.002 to 0.010 mg/dm^3). Concentrations higher than the above were seldom observed, e.g., in well B-5 in November 1977 (0.22 mg/dm^3) and in August 1979 (0.072 mg/dm^3). In both cases Pb content was 4 to 10 times higher than levels found in other wells. Single increases in Pb content (0.110 mg/dm^3) appeared in March 1979 in well B-10 and in well B-7 in May 1979 (0.28 mg/dm^3) - both wells outside the disposal influence zone.

The distribution of Pb in groundwater during disposal operations does not indicate any contribution from the disposal site. The temporary increases in Pb concentrations in some wells may have been due to sources other than the disposal site. The extremely high levels found in well B-5, located about 50 m from the disposal site, may implicate the refuse as the source of the pollution; however, increases observed in wells B-7 and B-10 are probably related to other factors. Although the pollution potential of Pb is great, as evidenced by the high concentrations found in laboratory leachates, the absence of high levels of Pb in water samples from wells around the disposal site is most likely due to lead's low leachability from the refuse.

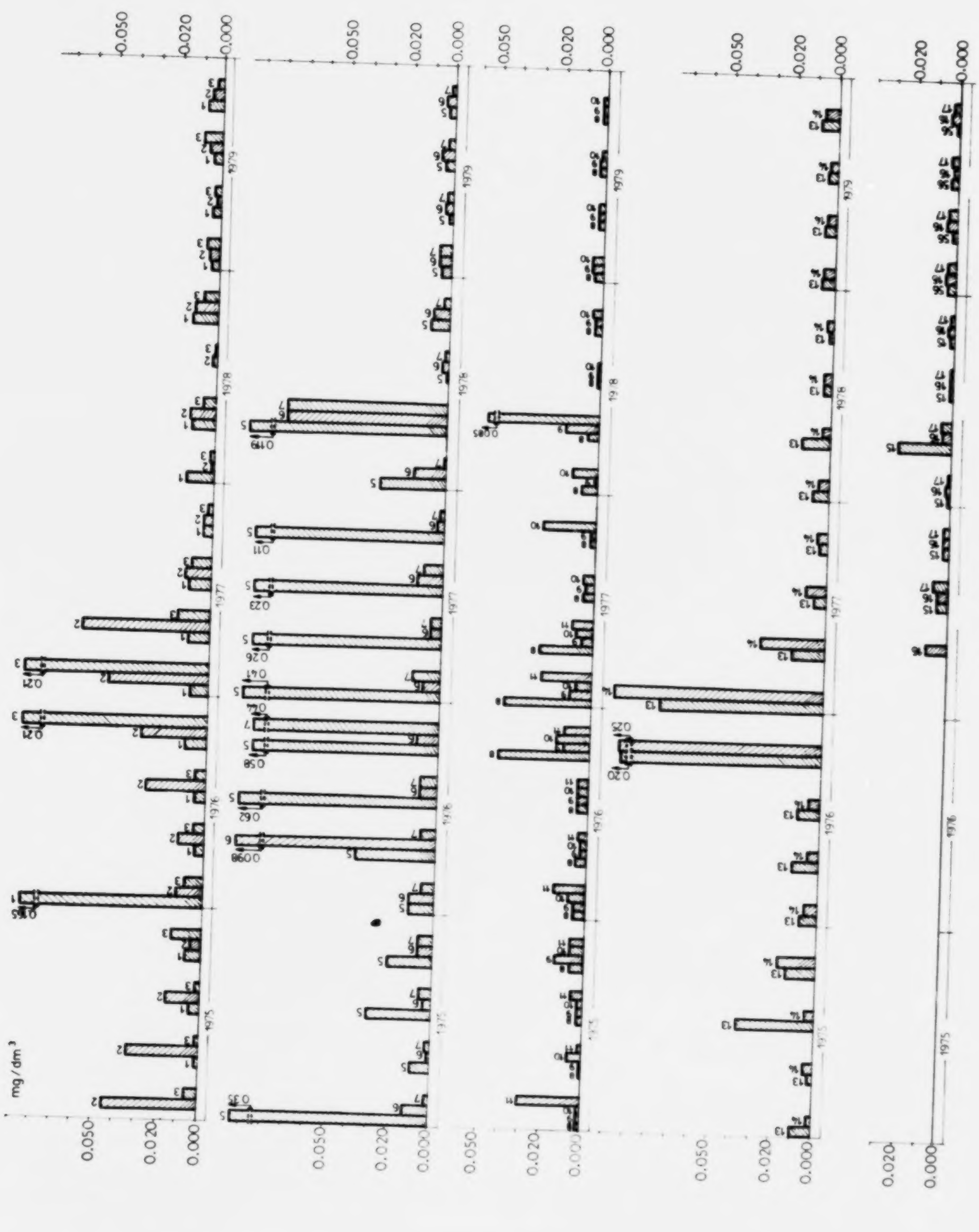


Fig. 9-36.The diagram of Cu content

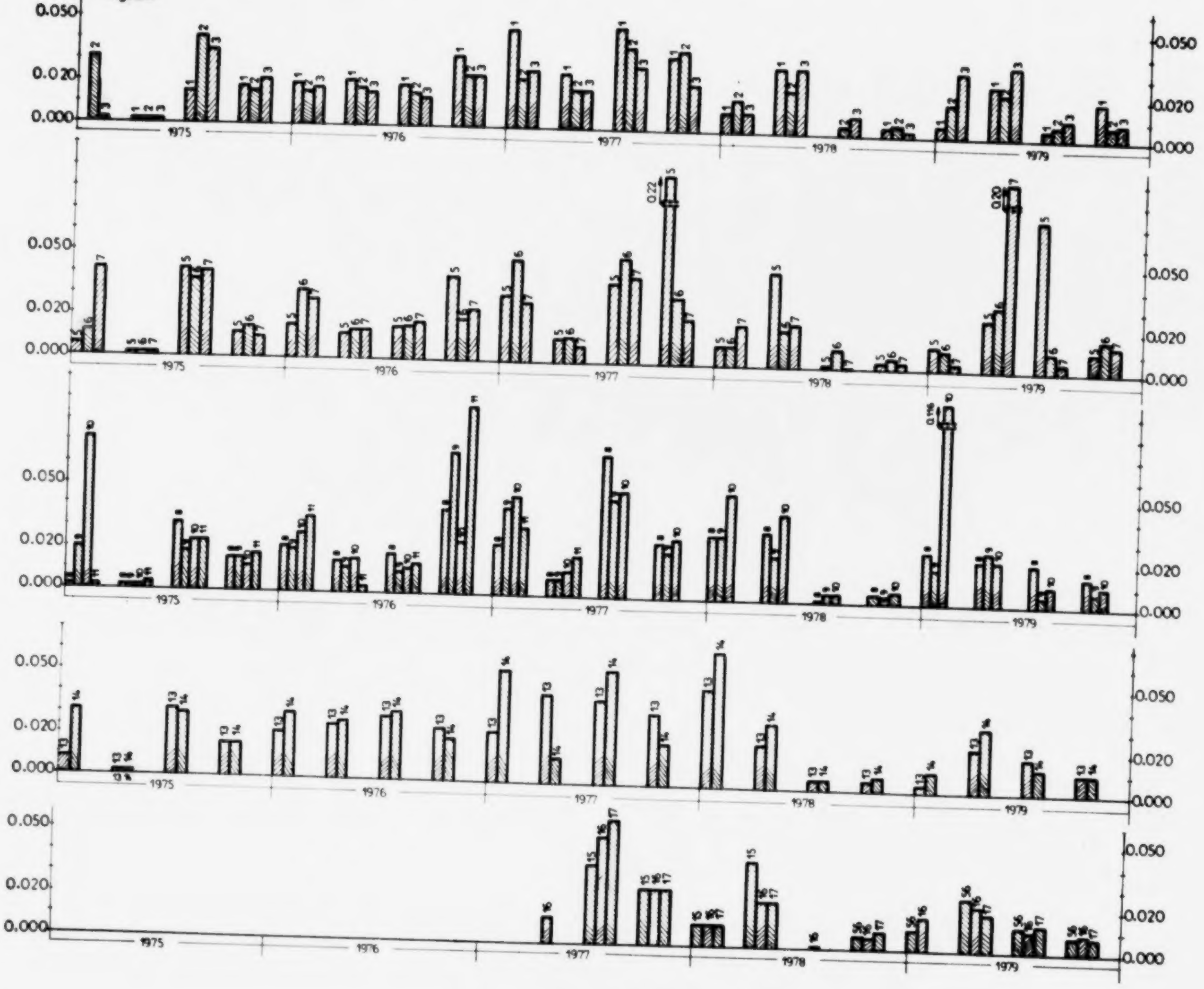


Fig.9-37. The diagram of Pb content

Chromium (Cr)

The content of Cr in laboratory leachates varied from 0.011 to 0.089 mg/dm^3 (average 0.036 mg/dm^3). The content of Cr in groundwater during disposal operations ranged from 0.002 to 0.008 mg/dm^3, except from September 1975 through March 1976 and in May 1977 when it was between 0.008 and 0.015 mg/dm^3. Temporary increases were observed in well B-5 in September 1977 (0.02 mg/dm^3) in well B-7 in June and December 1978 (0.01 mg/dm^3), in well B-17 in June 1978 (0.011 mg/dm^3), and in well B-2 in March 1979 (0.012 mg/dm^3). Temporary increases of Cr in the above wells, except in well B-5 were insignificant, about 30 to 50 percent higher. In well B-5, it was much higher (about 300 percent).

In light of the above it may be assumed that significantly higher Cr content in well B-5 was caused by the disposal operation. The lack of any increase in Cr in the wells situated within the disposal influence zone may be related to the small amount of Cr in the refuse. Slightly increased concentrations in well B-7 were probably due to other factors (even though it is north of the disposal site in the direction of groundwater flow), because few increases in levels of other components were observed in that well.

Arsenium (As)

The content of As in laboratory leachates varied from 0.008 to 0.133 mg/dm^3 and the average was 0.058 mg/dm^3.

During disposal operations As content in groundwater varied considerably at different times. Increased As concentrations appeared in all wells in June 1976, from November 1977 to September 1978, from April to August 1978 and in December 1978. During these periods, concentrations generally varied from 0.01 to 0.06 mg/dm^3, but sometimes reached 0.1 mg/dm^3. At other times, it was usually slightly higher than 0.008 mg/dm^3. Higher concentrations were occasionally observed in June 1976 in well B-12 (0.48 mg/dm^3), in January 1977 in well B-5 (0.44 mg/dm^3), and in well B-10 (0.30 mg/dm^3).

The distribution of As concentrations does not indicate that the disposal site impacted groundwater pollution. The absence of As was probably due to the small content of As in the refuse. The observed increases in As were probably related to other factors.

Strontium (Sr)

The content of Sr in laboratory leachates varied from 0.037 to 2.050 mg/dm^3, averaging 0.406 mg/dm^3. Until March 1976, Sr content in groundwater ranged from 0.05 to 0.15 mg/dm^3 with few exceptions. Higher concentrations of 0.2 mg/dm^3 were sporadically observed in some wells (B-14, B-2, B-5). In March 1976, the distribution of Sr gradually changed in certain wells; higher Sr concentrations were observed during various time periods. Longer lasting increases of Sr

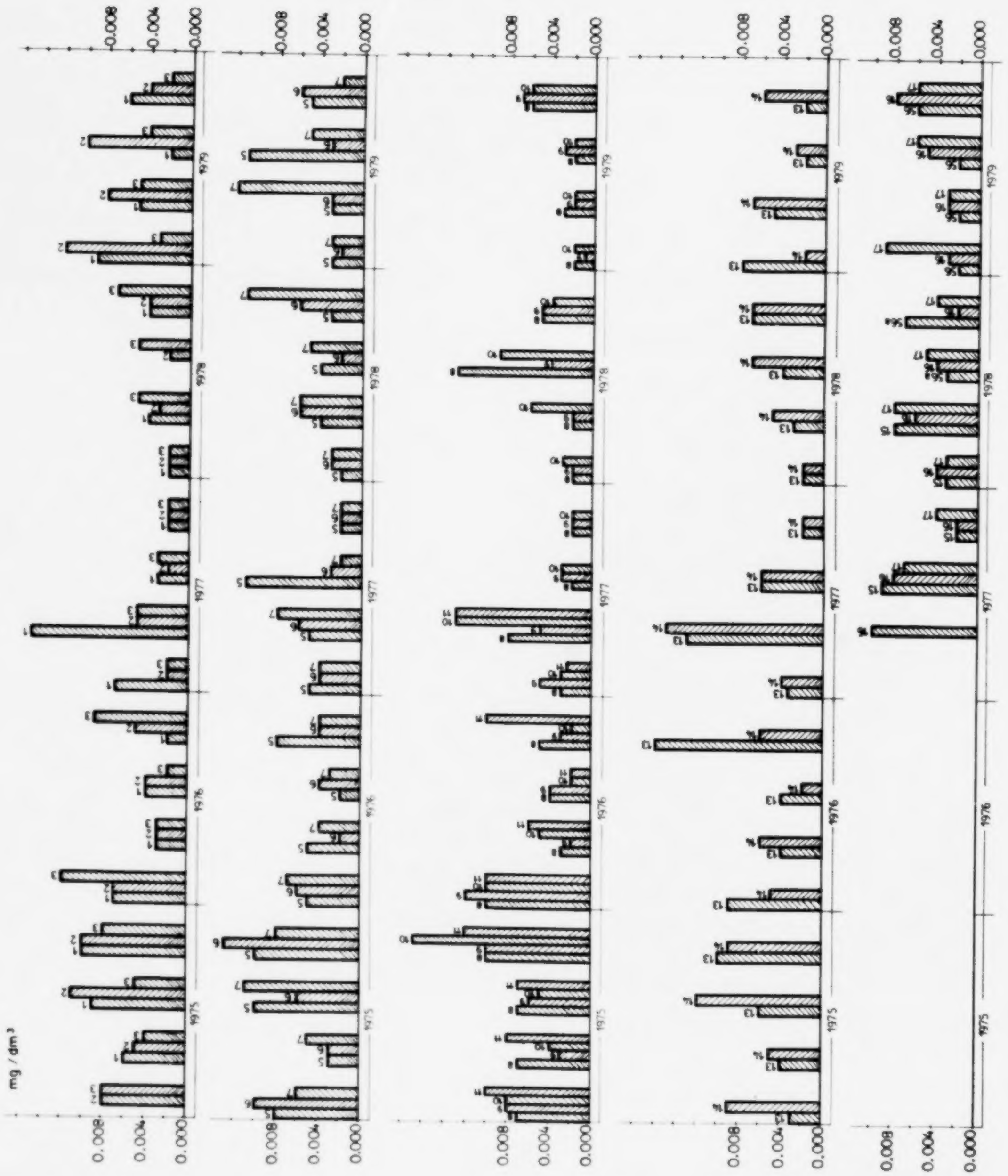


Fig. 9-38.The diagram of Cr content

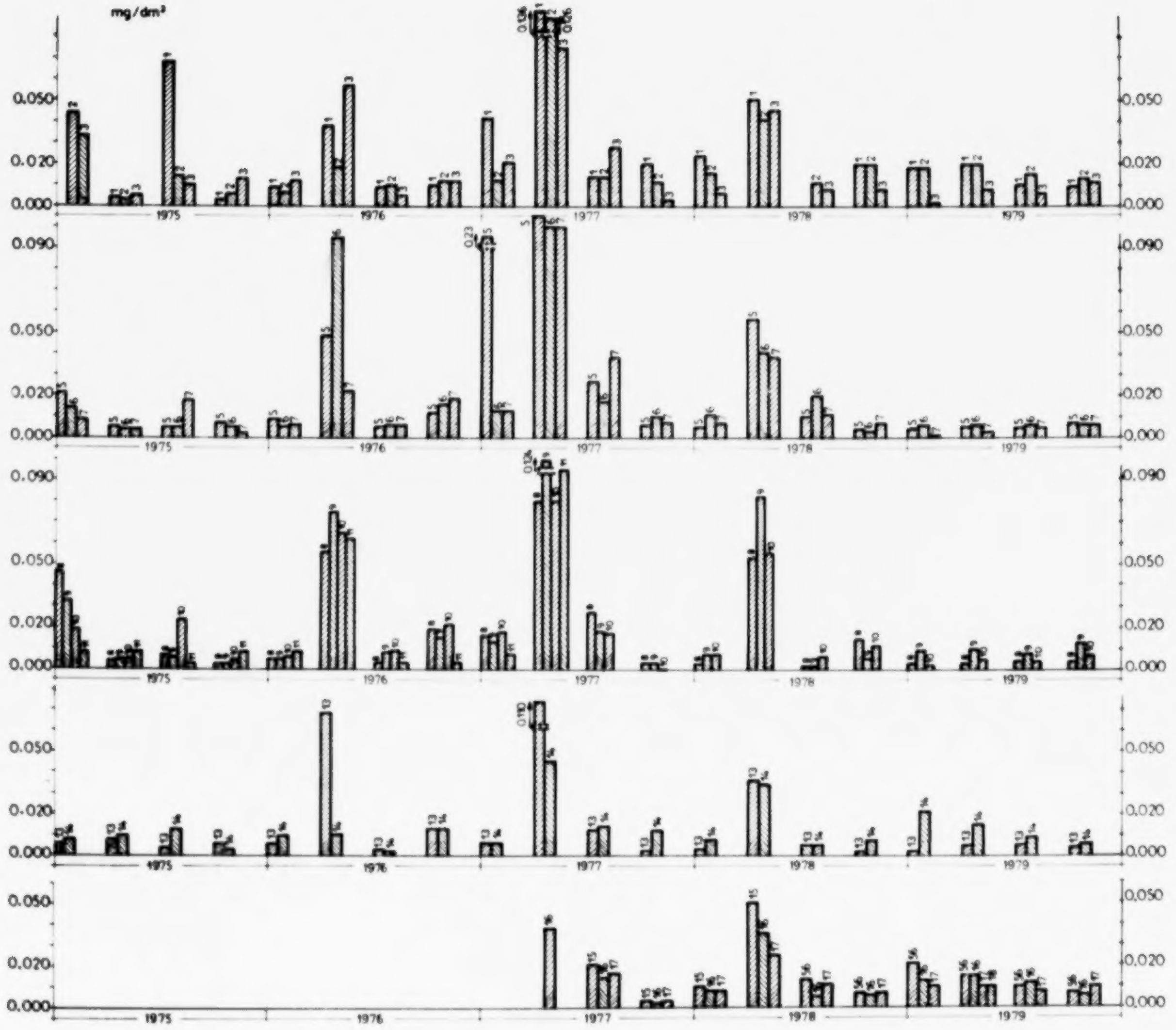


Fig. 9-39.The diagram of As content

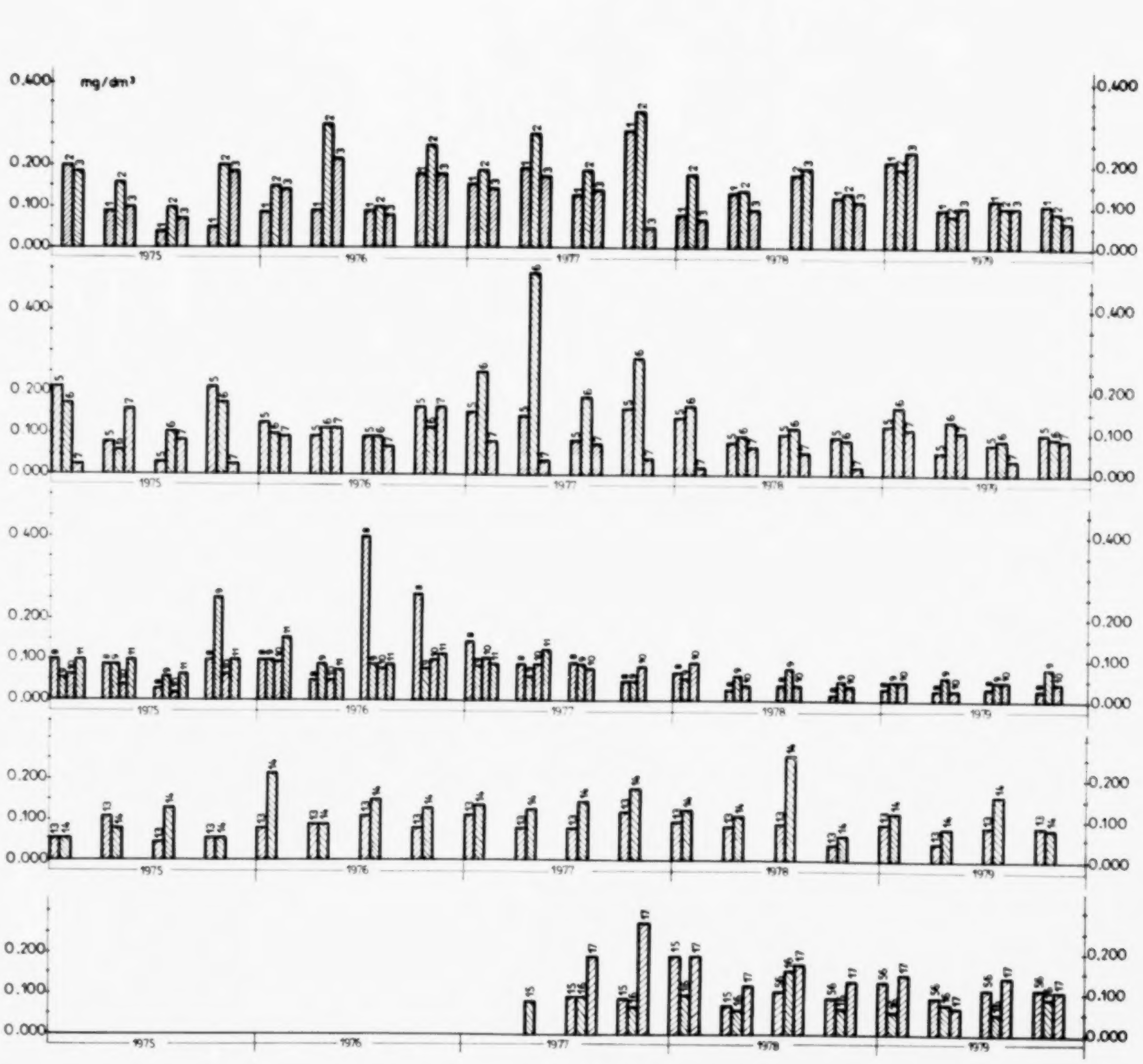


Fig.9-40.The diagram of Sr content

content were noticed in wells B-2 and B-6, but in wells B-1, B-3, B-5, B-8, B-14 and B-17 increased concentrations appeared intermittently.

In well B-2 Sr content increased significantly beginning in June 1976, but until January 1977, it appeared as a temporary increase. From March 1977 until March 1979, the levels increased steadily. First the concentration increased to 0.30 mg/dm^3 in June and to 0.25 mg/dm^3 in November 1976. Then from March through November 1977, it increased from 0.25 mg/dm^3 to a maximum of 0.335 mg/dm^3. Until March 1979 Sr content in this well lessened, and remained at a level of about 0.180 to 0.190 mg/dm^3.

In well B-6 increased Sr concentrations were observed continuously from January 1977 until April 1978. By May 1977, it increased from 0.275 mg/dm^3 to 0.490 mg/dm^3, and by April 1978 the level had decreased to 0.135 mg/dm^3, a level only slightly higher than in other wells at that time.

Increased Sr content (0.285 mg/dm^3) was observed in well B-1 in November 1977, but in April 1978, it was less significant (0.145 mg/dm^3). In March 1979, it rose again to 0.217 mg/dm^3.

In well B-3 increased Sr concentrations were found in April 1976 (0.215 mg/dm^3), in August 1978 (0.185 mg/dm^3), and in March 1979 (0.235 mg/dm^3). A single increase in well B-5 was observed in November 1977 (0.150 mg/dm^3). In well B-8 higher Sr content appeared from August 1976 when it reached 0.40 mg/dm^3 until January 1977 (0.20 mg/dm^3). In well B-17 increased Sr concentrations occurred in July 1977 and remained until the end of 1978. During that period the levels ranged from 0.180 to 0.199 mg/dm^3, and only once in November 1977 did it increase to 0.270 mg/dm^3. Additional singular increases were observed in well B-14 in August 1976 (0.400 mg/dm^3) and in November 1976 (0.260 mg/dm^3).

Based on the above results it may be concluded that increased concentrations of Sr in groundwater was caused by the disposal site. This influence was observed north of the disposal pits not more than 300 m away in the direction of groundwater flow. Singular increased concentrations of Sr noted in wells B-14 and B-8 were probably due to other factors. Large numbers of wells polluted by Sr illustrate high mobility of this pollutant and may prove to be one of the most hazardous.

Mercury (Hg)

The content of Hg in laboratory leachates varied from 0.6 to 10.9 μg/dm^3 averaging 5.17 μg/dm^3. During disposal operations the content of Hg in groundwater varied considerably.

During the first period of disposal operations (1975) as well as in the final phase (from October 1978 until the end of 1979) Hg content in all wells most frequently ranged from 0.4 to 0.5 μg/dm^3.

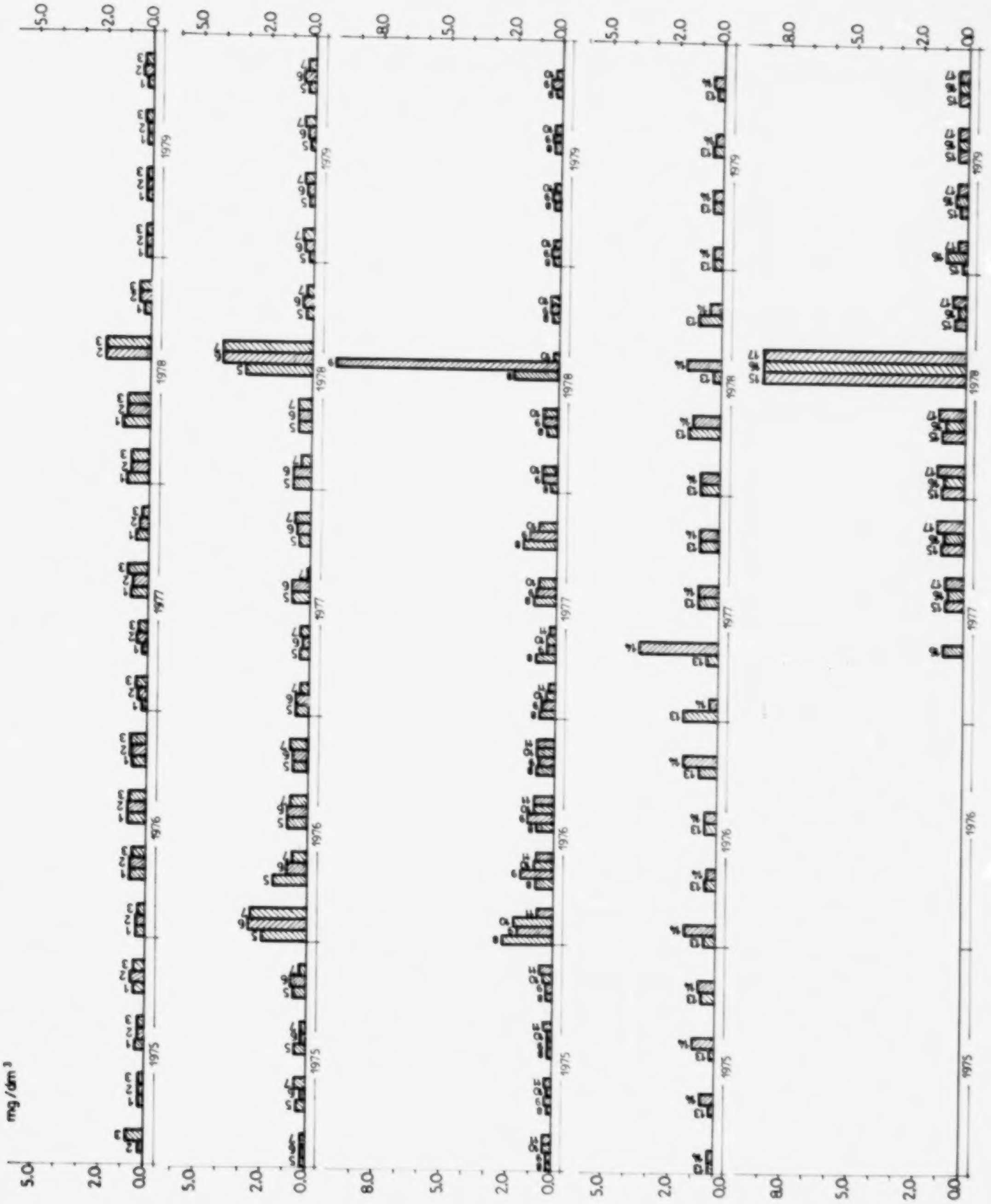


Fig.9-41.The diagram of Hg content

Throughout 1976 and until August 1978 concentrations were much higher and except during early 1976 and in August 1978, the levels were in most cases 0.8 to 1.5 $\mu g/dm^3$. Hg content early in 1976 in the majority of wells (B-5, B-6, B-7, B-8, B-9, B-10, B-14) was from 1.6 to 2.6 $\mu g/dm^3$ and in August 1978 it ranged from 2.0 to 10.0 $\mu g/dm^3$.

Distribution of Hg content in groundwater, regardless of time or site, does not indicate disposal as a factor responsible for the pollution. Concentrations of Hg in groundwater higher than in laboratory leachates were observed in wells located in the direction opposed to groundwater flow. This suggests that the pollution must be due to other factors.

Cadmium (Cd)

The content of Cd in laboratory leachates varied from 0.005 to 0.056 mg/dm^3; the average was 0.024 mg/dm^3. During disposal operations Cd content in groundwater did not display considerable variations. Until October 1978, concentrations of cadmium in all tested wells most often varied from 0.001 to 0.003 mg/dm^3. After December 1978 Cd concentrations increased slightly in some wells, but the average did not exceed 0.005 mg/dm^3. Higher content of Cd was observed in wells B-1, B-2, B-3, B-5 and B-6.

In well B-1 increased concentrations of Cd (0.006 to 0.009 mg/dm^3) appeared in December 1978 and remained at those levels until the end of observations. In well B-2, as in B-1, increased concentrations (0.007 to 0.008 mg/dm^3) were observed from December 1978 to August 1979. In well B-3 higher Cd concentration (about 0.01 mg/dm^3) appeared between March and August 1979. High levels occurring as temporary increases were observed in well B-6 in December 1978 (0.009 mg/dm^3) and December 1979 (0.007 mg/dm^3) and in well B-5 in March and December 1979 (0.006 mg/dm^3).

While analyzing the above data it may be assumed that part of the increase in Cd content in the groundwater 200-300 m north of the disposal site may be attributed to the refuse. In that part of the aquifer outside the disposal influence zone, no increase of Cd in the groundwater was observed. The low level of pollution was probably due to low concentrations of Cd in the refuse.

Molybdenum (Mo)

The content of Mo in laboratory leachates varied from 0.003 to 0.029 mg/dm^3 and its average was 0.017 mg/dm^3.

During disposal operations Mo content in groundwater generally varied from 0.001 to 0.005 mg/dm^3, except in November 1978 when the levels varied from 0.05 to 0.45 mg/dm^3. Only in wells B-1, B-2, B-3, B-7, B-9, B-10, were periodic increases observed.

Increased concentrations of Mo were found simultaneously in the above wells by the end of 1976 and from April to June 1978. In well

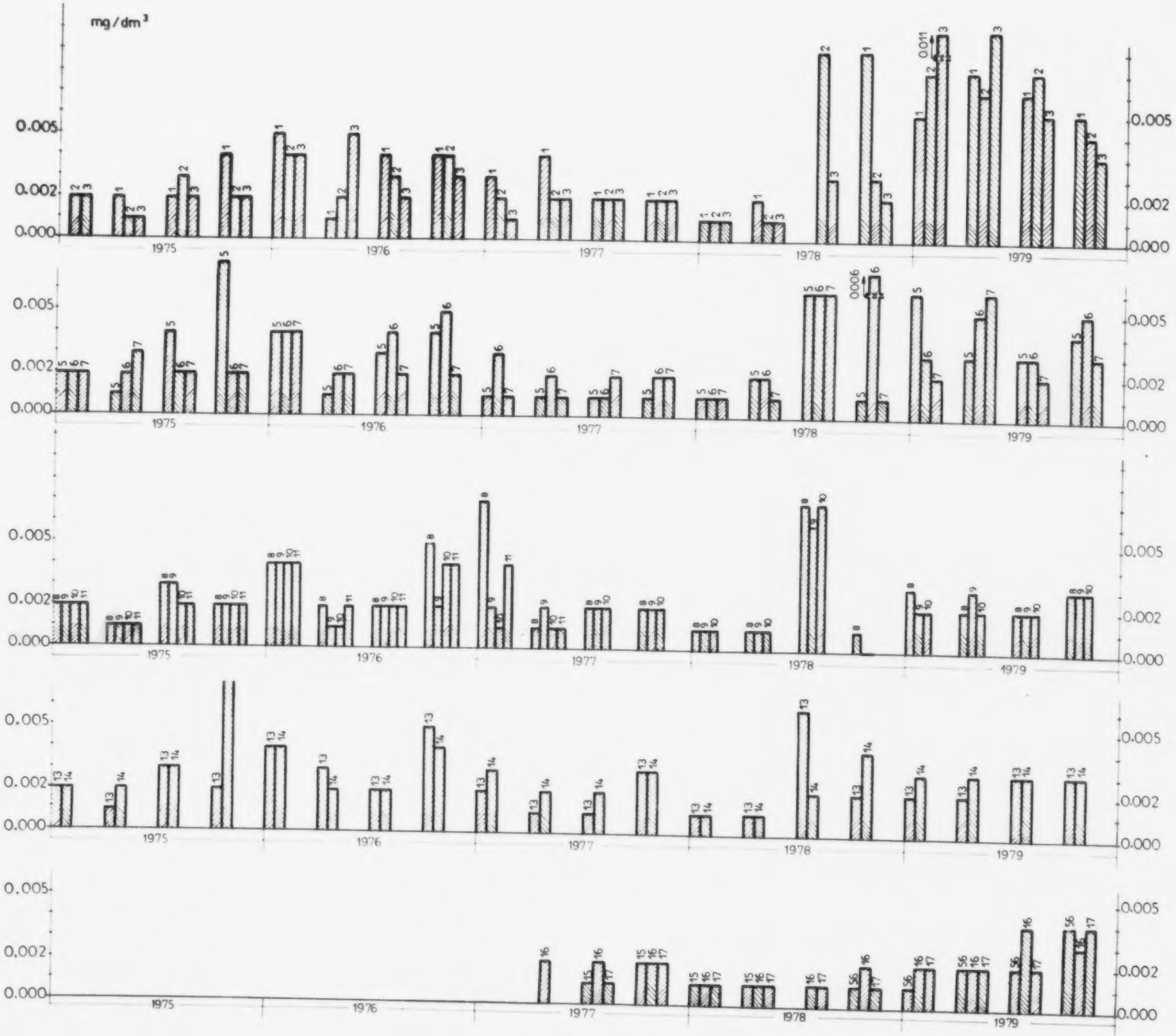


Fig. 9-42.The diagram of Cd content

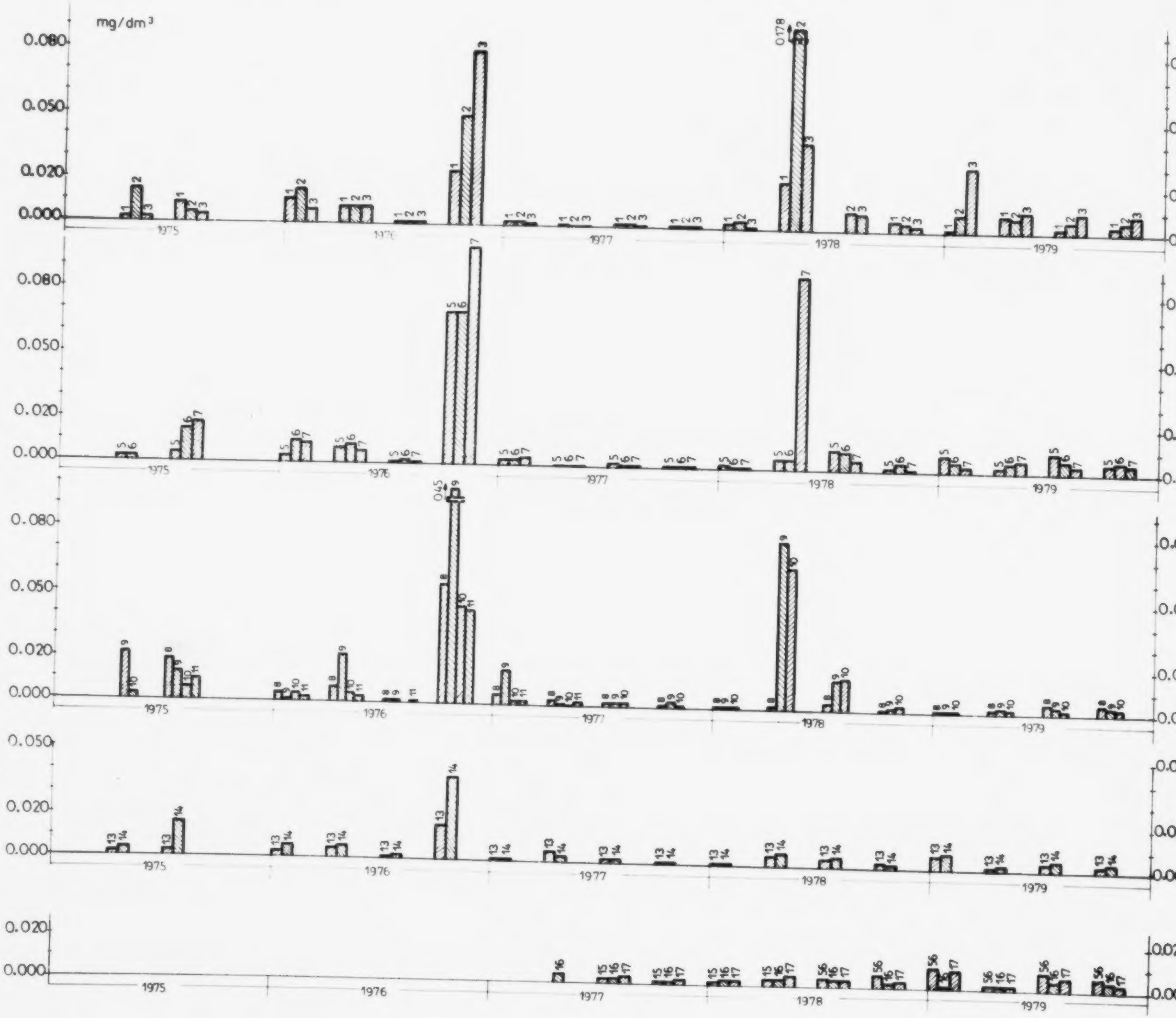


Fig.9-43.The diagram of Mo content

B-1 Mo content was 0.019 to 0.025 mg/dm^3, in well B-2 0.185 to 0.172 mg/dm^3, and in well B-3, 0.030 to 0.050 mg/dm^3, in wells B-9 and B-10 (0.150 mg/dm^3 to 0.125 mg/dm^3). Levels in other wells did not exceed 0.008 mg/dm^3.

It may be concluded that the impact of disposal on Mo content in groundwater was not demonstrated. High concentrations, above values found in laboratory leachates were observed in three wells located within the zone of clear disposal influence and in two wells outside this zone. The influence of disposal on pollution from molybdenum is doubtful, but was proved possible by its presence in laboratory leachates.

Boron (B)

The content of B in laboratory leachates varied from 0.095 to 3.600 mg/dm^3, averaging 0.855 mg/dm^3. From the beginning of disposal operations in 1975, until June 1976 B concentrations in groundwater did not generally exceed 0.03 mg/dm^3. From then until the end of the investigation, the content in all tested wells was somewhat higher and ranged from 0.03 to 0.08 mg/dm^3. Additionally, in wells B-1, B-6, B-8, B-13 and B-14, temporary increases of B were observed.

In well B-6, a continuously high content of B (0.100 to 0.200 mg/dm^3) was seen early in 1977 and remained through the end of 1979. In well B-1 higher concentrations (0.136 mg/dm^3) were observed for a short period of time (March through May 1977). Singular increases in B content were found in well B-8 in August 1976 (0.142 mg/dm^3) and in May 1977 in wells B-13 and B-14 (0.113 mg/dm^3 and 0.154 mg/dm^3, respectively).

Based on the above data it may be concluded that levels 5 to 6 times higher than normal observed for three years in well B-6, as well as in B-1, were caused by the disposal site. Small increases in B concentration measures in wells B-8, B-13, and B-14 were probably due to other sources of pollution.

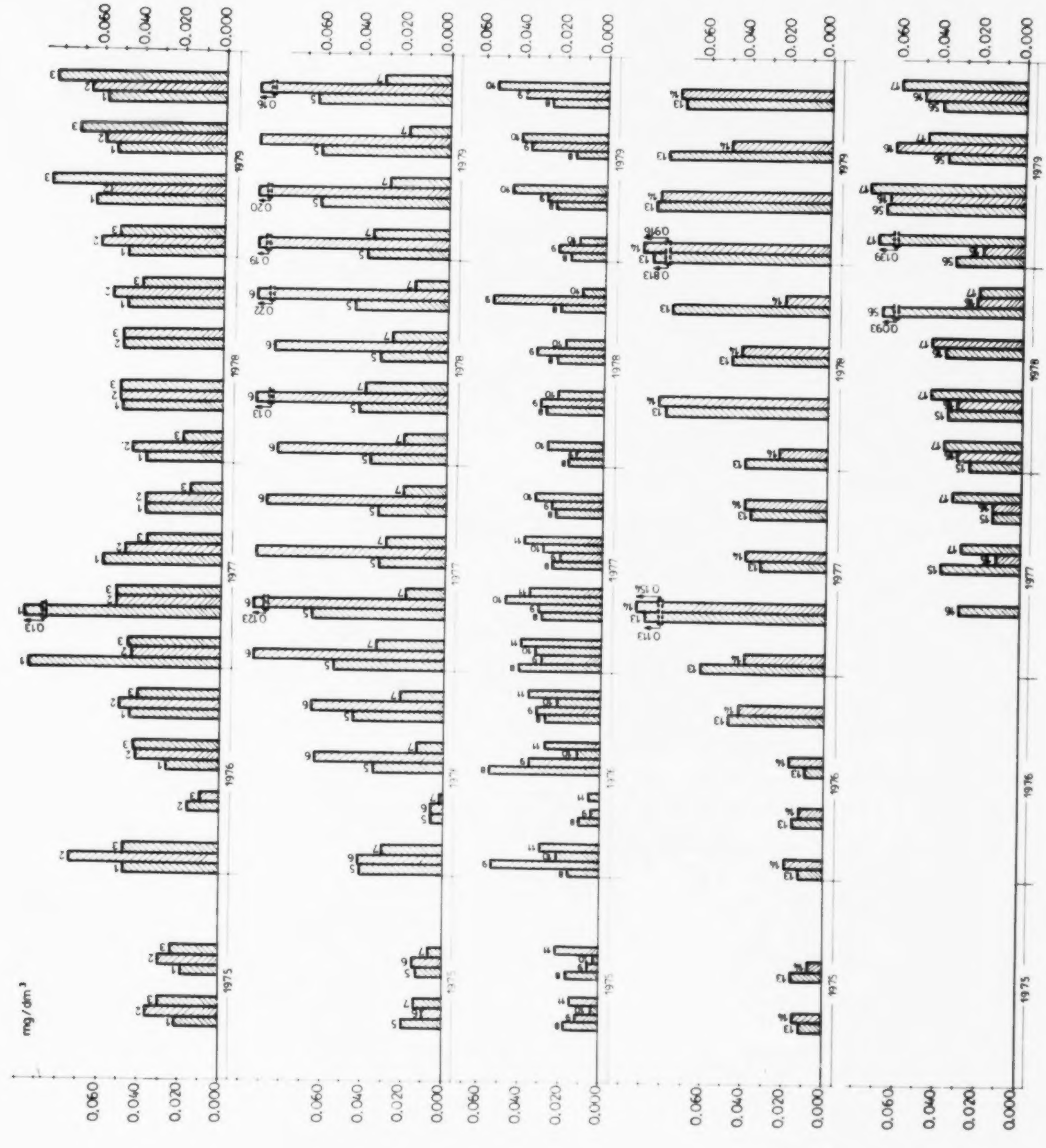


Fig. 9-44.The diagram of B content

SECTION 10

STATISTICAL ANALYSIS OF HYDROCHEMICAL TESTS

In order to verify conclusions of the effects of refuse on groundwater quality, three principal pollutants (TDS, Cl and SO_4) were statistically analyzed. Statistical methods were utilized to formulate a model for the pollution and present proper statistical hypotheses, verify these hypotheses through selected tests, and discuss the results.

The tests comprised measurements of these components between 1974 and 1979. For analysis of digital data, the programs including basic statistical analysis and analysis of variance for binary classification without replications were applied. A discussion of the computed results are presented in the conclusions.

THEORETICAL BASIS

Statistical Model

P - the disposal area
T - time passed since the start of disposal operations.

The assumption is that pollution of groundwater by a given component, at point p_ε P, at moment t_ε $<0,T>$, is a random variable x (t,p) with an expected value μ (t, p), variance β^2(t,p) and distribution f_t, p(x). If the disposal operations do not affect groundwater quality, then for p = pj, values μ (t, pj), σ^2(t, pj) and the distributions f_t, p(x) should be the same for each t_ε $<0,T>$. The effect of disposal on groundwater quality can then be investigated by verifying the following hypothesis:

$$H_o : \bigwedge_{p \quad P} \quad \bigwedge_{t_i, \; t_j} <0,T> \quad \mu(t_i, p) = \mu(t_j, P)$$

(the symbol $\wedge$ is read as: for each).

An hypothesis formulated in this manner is usually verified using tests for significance. Choice of the tests depends on random variable x (t, p) assumptions, the measurements diagram and their number. The applied scheme of sampling justifies the choice of variance analysis to tests and disprove the hypothesis H_o. In order to apply other tests or verify other hypotheses, related for example, to the distributions f_t, $p(x)$, basic tests characteristics (which are known variables of the $x(t, pj)$ variable for pj and the $x(t_i, p)$ variable for t_i) were determined. The formulae used in calculation programs for basic analysis and variance analysis are given below. In order to simplify the notation the symbols "i" for "t_i" and "j" for "pj" were introduced.

Basic Analysis

We assumed that $\{x_i\}$, $i = 1, \ldots, n$ means a collection of measurements which were known variables of the random variable x. Basic statistical assessments of the random variable x include:

Average:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

Variance:

$$s^2 = \frac{1}{n-1} \sum_{i=1}^{n} x_i = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n}$$

Standard deviation:

$$s = \sqrt{s^2}$$

Half - interval of confidence for the average:

$$d = t\alpha \cdot S_{\bar{x}}$$

where:

$S_{\bar{x}} = \frac{S}{\sqrt{n}}$ standard deviation of the average,

$t\alpha$ - value of statistics of t - Student for n-1 degree of freedom and the condifence level $1-\alpha$.

Confidence interval:

$$(\bar{x} - d, \quad \bar{x} + d).$$

Variance analysis

As a result of tests the observation matrix $\{x_{ij}\}$, $i = 1,\dots, r$, $j = 1,\dots k$, were obtained,

where:

r = number of measurements (tests)
k = number of wells.

The mathematical model for variance analysis is expressed by the equation:

$$x_{ij} = \mu + (\mu_i - \mu) + (\eta_j - \mu) + \varepsilon_{ij}$$

$$i = 1,\dots, r, \quad j = 1,\dots,k$$

where:

- μ, μ_i, η_j are constants, with:

$$\sum_{i=1}^{r} (u_i - u) = \sum_{j=1}^{k} (\eta_j = \mu) = 0$$

- random variables ε_{ij} are idependent and have normal distribution with the average zero and identical variance σ^2.

Estimators of the model (1) components are: $\hat{\mu}, \hat{\mu}_i, \hat{\eta}_j$, respectively, calculated from the test with the following equations:

$$\hat{\mu} = \bar{x}_{..} = \frac{\sum_{i=1}^{r} \sum_{j=1}^{k} x_{ij}}{r\,k}$$, total average,

$$\hat{\mu}_i = \bar{x}_{i.} = \frac{\sum_{j=1}^{k} x_{ij}}{k}$$, average for measurements

$$\hat{\eta}_j = \bar{x}_{\cdot j} = \frac{\sum_{i=1}^{r} x_{ij}}{r}, \text{ average for wells.}$$

The total sum of squares is divided into three independent addends which represent the influence of each component on the model (8).

Total sum of squares:

$$G = \sum_{i=1}^{r} \sum_{j=1}^{k} (x_{ij} - \bar{x}_{\cdot\cdot})^2 = \sum_{i=1}^{r} \sum_{j=1}^{k} x_{ij}^{\,2} = \frac{\left(\sum_{i=1}^{r} \sum_{j=1}^{k} x_{ij} \right)^2}{r\,k}$$

Sum of squares for measurements:

$$R = k \sum_{i=1}^{r} (\bar{x}_{i\cdot\cdot} = \bar{x}_{\cdot\cdot})^2 = \frac{\sum_{i=1}^{r} \left(\sum_{j=1}^{k} x_{ij} \right)^2}{k} = \frac{\left(\sum_{i=1}^{r} \sum_{j=1}^{k} x_{ij} \right)^2}{r\,k}$$

Sum of squares for wells:

$$T = r \sum_{j=1}^{k} (\bar{x}_{\cdot j} - \bar{x}_{\cdot\cdot})^2 = \frac{\sum_{j=1}^{k} \left(\sum_{i=1}^{r} x_{ij} \right)^2}{r} = \frac{\left(\sum_{i=1}^{r} \sum_{j=1}^{k} x_{ij} \right)^2}{r\,k}$$

Sum of squares for random deviations:

$$E = G - R - T$$

Diagram of Variance Analysis

	Number of Degrees of Freedom	Sum of squares	Average square	Expected values of average squares	F cal.
Wells	k-1	T	$S_T^2 = \frac{T}{k-1}$	$\sigma^2 + r\frac{\sum_{j=1}^{k}(\eta_j - u)^2}{k-1}$	$\frac{S^2T}{S^2}$
Measurements	r-1	R	$S_R^2 = \frac{R}{r-1}$	$\sigma^2 + k\frac{\sum_{i=1}^{r}(u_i - u)^2}{r-1}$	$\frac{S_R^2}{S^2}$
Random deviation	(r-1) (k-1)	E	$S^2 = \frac{E}{(r-1)(k-1)}$	σ^2	
Total	rk-1	G			

The hypothesis $H_o = \mu_1 = \mu_2 = \mu_2 = \ldots = \mu_r$, regarding the identity of averages for measurements in time is tested and disproved using the F Test.

$F_{cal.} = \frac{S^2T}{S^2}$ is compared with the value read from the table of F distribution for $V_1 = k-1$, $V_2 = (k-1)\ (r-1)$ degrees of freedom and the adopted significance level α.

If:

$F_{cal.} \geqslant F_{TAB1}$ - we refuse the hypothesis H_o,

$F_{cal.} < F_{TAB1}$ - no basis to refuse H_o.

The hypothesis $H_o = \eta_1 = \eta_2 = \ldots = \eta_k$, about identity of averages for wells is checked in the same manner.

The t - Duncan test can also be used to examine the significance of differences between averages. In order to compare a group of averages $\{\bar{x}_{i..}\}$, $i = 1, \ldots r$, (each is determined from k replications) it is necessary to calculate:
Standard deviation of averages' difference:

$$S_D = S \cdot \sqrt{\frac{2}{k}}$$

Empirical value of maximum difference of averages:

$$D_e = \max_{i=1,r} \left\{ x_i . \right\} - \min_{i=1,\dots,r} \left\{ \bar{x}_1 . \right\}$$

Limiting value of r averages' difference for the significance level α :

$$D_{gr} = t_\alpha^r \cdot S_D$$

where: $t_\alpha{}^r$ is a value of the t - Duncan test for r averages and the number of degree of freedom of the determined standard deviation S and significance level α .

The t - Duncan test enables the determination of groups of averages which are not significantly different from each other, and which include $m < r$ elements. In order to calculate limiting differences it is necessary to take the correct value of $t_\alpha{}^m$ from the t-Duncan distribution tables.

DISCUSSION OF CALCULATION RESULTS

Basic statistical analysis and variance analysis were performed for three pollutants: TDS, Cl and $S0_4$. Calculations were based on data from 86 series of measurements on samples from 11 wells. Because of the lack of some data only 72 complete series of samples (for all 11 wells) were used for the variance analysis. Results of the calculations are included. The averages of data are presented on diagrams. All hypotheses were verified at a significance level = 0.05. Variance analysis of the three pollutants showed that differences between wells and differences between measurements are statistically significant.

Results of the F Test are as follows:

Name of pollutant	For wells			For measurements		
	F cal	F tabl.	significance	F cal.	F tabl.	significance
TDS	31.1	1.845	x	5.89	1.31	x
Cl	21.62	1.845	x	7.737	1.31	x
$S0_4$	41.14	1.845	x	6.88	1.31	x

Application of the t-Duncan test to form homogenous groups of the wells' averages gave the following results:

Name of pollutant	Group I (Well No.)	Group II (Well No.)	Group III (Well No.)	Group IV (Well No.)	Group V (Well No.)
TDS	8	7	5,10,9,13	14,3	1,2,6
Cl	8	5,7,10, 13,9	14,3	1,2	6
SO_4	7,8	10,5	9,13	14,6,3	1,2

Based on the above data it may be assumed that the lowest levels of each tested component were observed in well 7 or 8. The highest concentrations of these pollutants were observed in wells 1, 2 and 6. Because of the larger number of measurement averages it was difficult to group wells. Therefore, measurement averages were grouped according to the year of the test.

The hypothesis concerning homogeneity of averages, for measurements taken in one year periods, was verified. The results are given in Table 10-1. In light of the data presented in Table 10-1 the null hypothesis was rejected. Application of the t-Duncan test to verify the significance of the maximum difference between averages of all years cannot be the basis for rejecting the homogeneity hypothesis for that group of averages. Maximum averages do not form a homogenous group in statistical meaning. The range of pollutant level variability increases significantly as time passes.

Averages by one year periods were determined for each well. Values of these averages with a 95 percent confidence interval are presented in Figures 10-1 to 10-3. Results of testing the significance of maximum differences between one year averages for the five-year period, for each well and for all wells, are detailed in Tables 10-2 to 10-4. From these data, one may conclude that no significant differences between the five yearly averages (1975 through 1979) exist in wells:

7, 8, 9	for TDS
7, 8	for Cl
8	for SO_4.

In the remaining wells, average concentrations increase every year, and the differences are statistically significant. The average concentrations from all wells by a yearly period, also increases significantly. The greatest differences are observed between yearly averages in wells 1, 2 and 6. These increases in levels of pollutants may also be expressed as percentage increases as compared to levels found in 1975. These percentage ratios are also presented in Tables 10-2 to 10-4.

Statistical analysis of TDS, Cl and SO_4 concentrations indicated that:

- there are statistically significant increases of pollutant concentrations during successive years of disposal operations;
- in some wells within the disposal influence zone, no significant differences were observed, and;
- statistically significant interrelationships exist between the pollutants' content increase and the location of the well.

It may be concluded that the average increases in TDS, Cl and SO_4, estimated by statistical methods, were caused by the disposal operations, which confirms the expectation. The areas of greatest influence were located in the vicinity of wells 1, 2 and 6. It should be remembered that these conclusions are based on statistical methodology with a 95 % level of confidence. Additional study is necessary to raise the hypothesis to the range of a thesis.

CONCLUSIONS

Application of statistical methods in preparing and analyzing of pollutants' concentration is obligatory in investigating coal wastes disposal effect on groundwater quality. These methodologies enable:

- the correct calculation of average values of pollutant content,
- the determination of the statistical significance of observed changes and their quantitative evaluation, and
- the collection of justifiable conclusions to the investigated problem.

Conclusions obtained from the statistical analysis would be more complete if there were a control group of measurements made prior to disposal operations. These methods of data estimation should be completed with the analysis of time sequences. This would allow an estimate of trends of the pollution and the determination of periodic fluctuations.

Table 10-1

Analyses of Null Hypotheses Related to Averages for Measuring with t - Duncan Test

$H_o : \bar{x}_i = \bar{x}_{i+1} = \dots = \bar{x}_{i+16}$, where i = 1, ..., 5

$H_o : \bar{x}_{min}(75) = \bar{x}_{min}(76) = \bar{x}_{min}(77) = \bar{x}_{min}(78) = \bar{x}_{min}(79)$

$H_o + \bar{x}_{max}(75) = \bar{x}_{max}(76) = \bar{x}_{max}(77) = \bar{x}_{max}(78) = \bar{x}_{max}(79)$

Name of characteristic		1975	1976	1977	1978	1979	
TDS$^{(1)}$	max.	212.09	287.45	320.73	314.73	366.92	S_D = 36.69
	min.	117.18	138.00	171.91	178.73	192.77	D gr(17)=88.79
	Differences	94.91 x	149.45 x	148.82 x	136.00 x	174.15 x	D gr(5) =79,97
Cl $^{(1)}$	max.	18.91	23.64	31.64	44.60	51.15	S_D = 4.87
	min.	13.41	13.54	20.64	21.64	18.08	D gr(17)=11.78
	Differences	5.49	10.10	11.00	22.96 x	33.07 x	D gr(5) = 10.62
$SO_4^{(1)}$	max.	67.13	83.82	71.20	127.64	147.15	S_D = 16.04
	min.	33.36	37.64	49.04	49.18	56.67	$D_{gr}(17)$ = 38.8
	Differences	33.77	46.19 x	22.16	78.46 x	90.55 x	D gr (5) = 34.96
TDS$^{(2)}$	192.77-117.18 = 75.59				366.92-212.09 = 153.83 x		
Cl $^{(2)}$	18.08-13.41 = 4.67				51.15- 18.91 = 32.24 x		
$SO_4^{(2)}$	56.67-33.36 = 23.31				147.15- 67.13 = 80.02 x		

1 - Differences are compared with $D_{gr}(17)$.

2 - Differences are compared with $D_{gr}(5)$.

x - Differences statistically significant.
Each average is calculated from 11 data points.

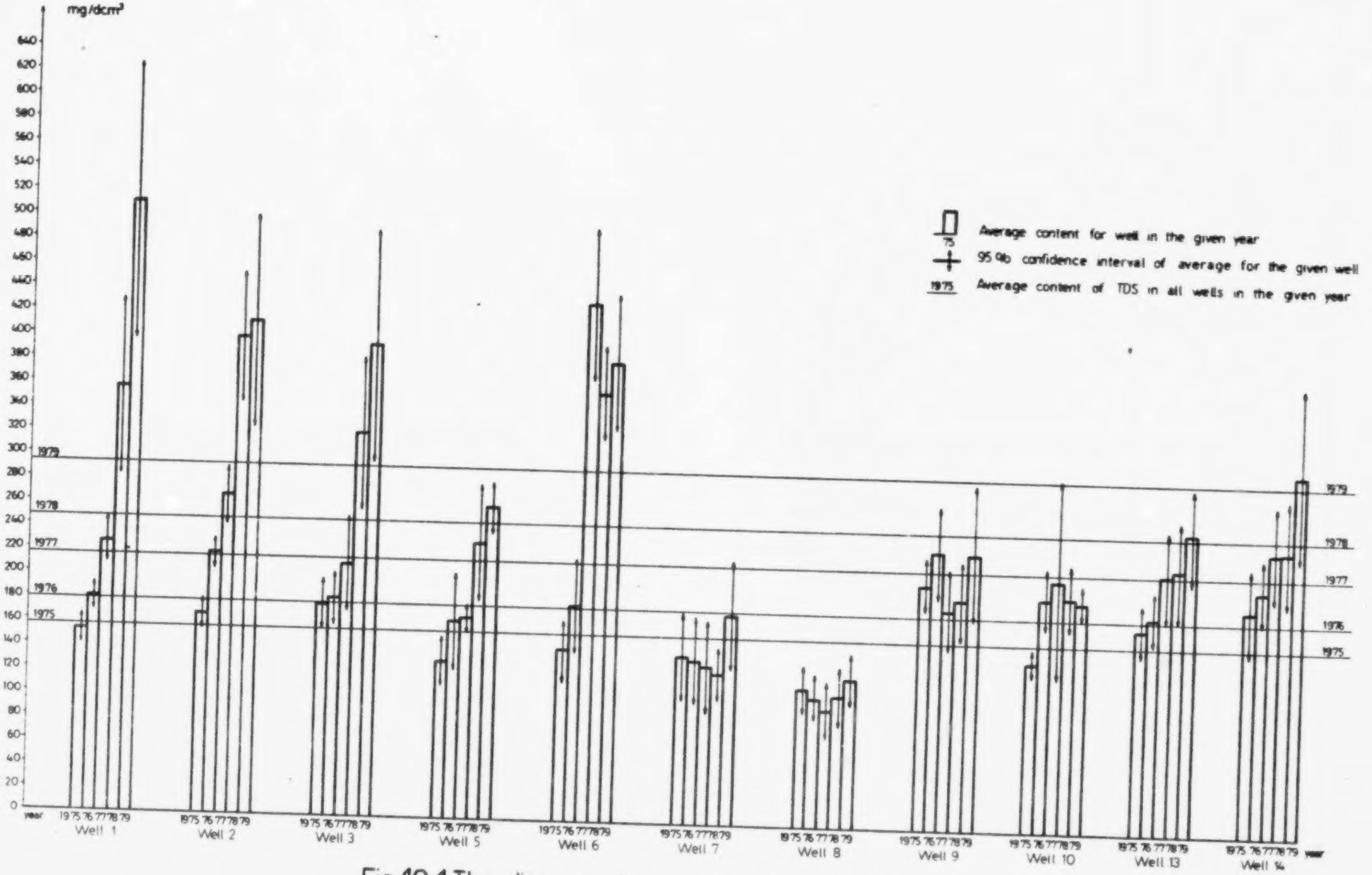


Fig.10-1.The diagram of average TDS content in particular wells.

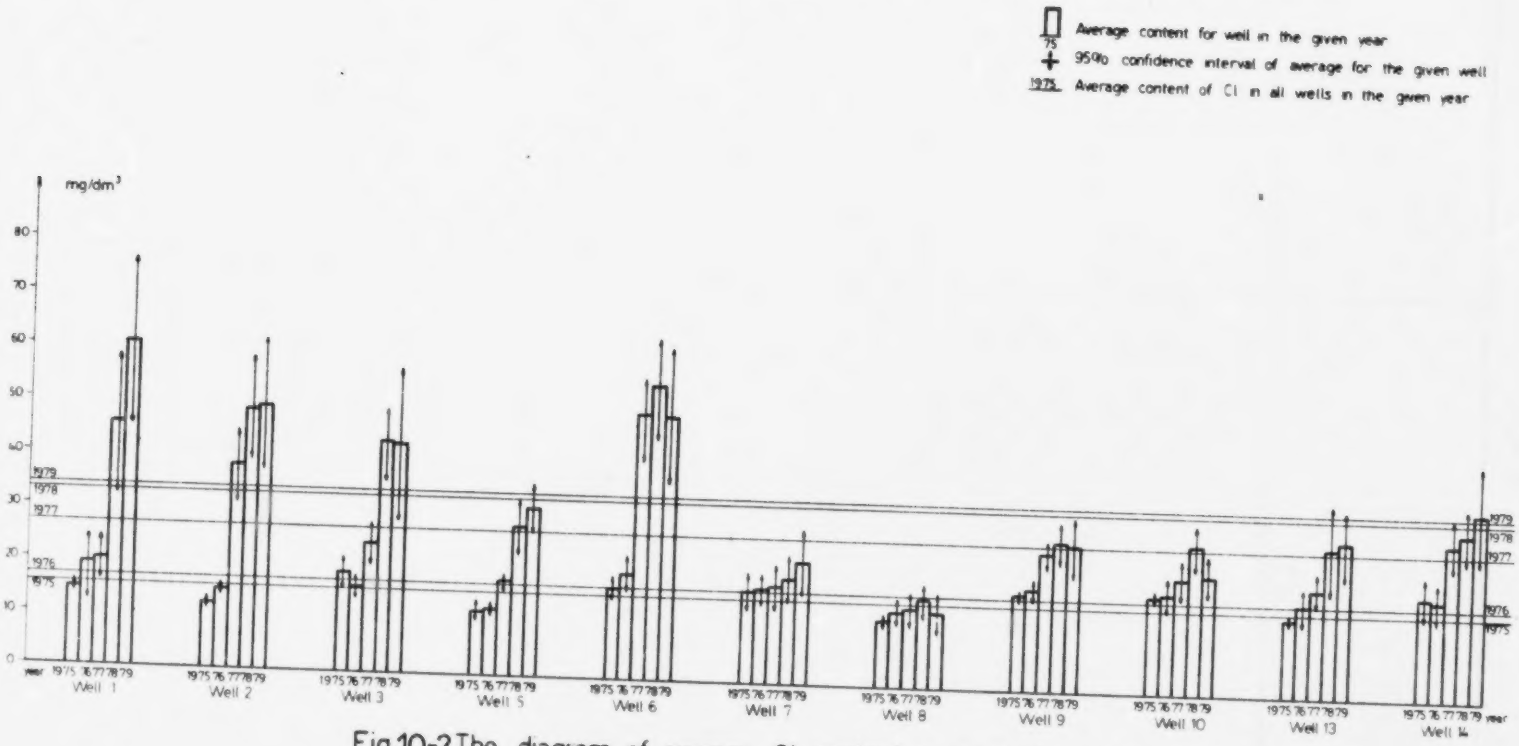


Fig.10-2.The diagram of average Cl content in particular wells.

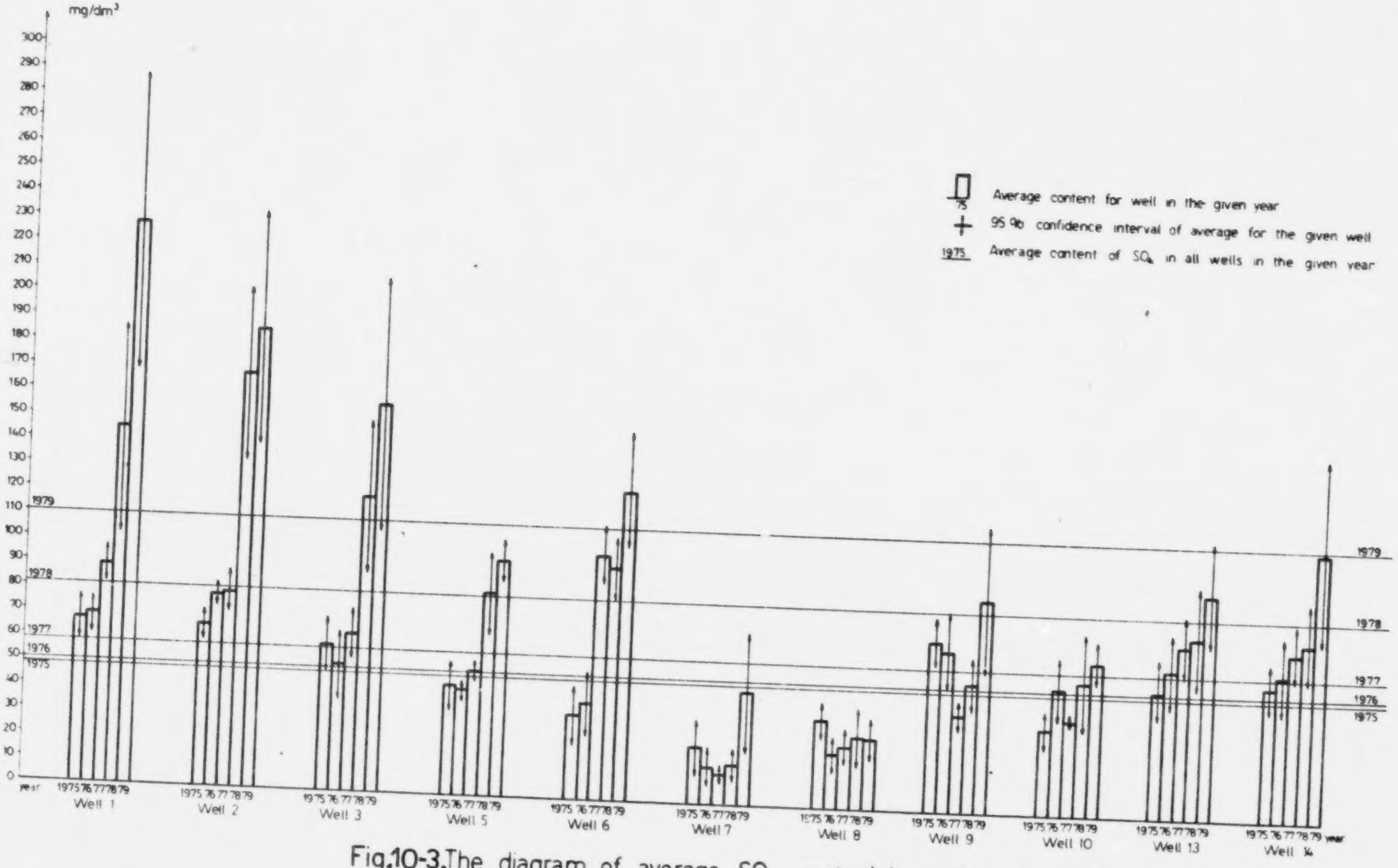


Fig.10-3.The diagram of average SO_4 content in particular wells.

Table 10-2. Average Content of TDS (in mg/dm^3) and Dynamics of Percentage Increase as Compared to 1975

Number of well	1975	1976	1977	1978	1979	Maximum difference
1	153.13 100	180.61 118	226.88 148	356.92 233	511.6 334	358.47 x
2	167.06 100	218.00 130	267.23 160	398.59 239	412.59 247	245.54 x
3	177.18 100	182.78 103	211.47 119	320.23 181	394.00 222	216.82 x
5	130.88 100	165.05 126	167.88 128	230.82 176	261.29 200	130.41 x
6	142.41 100	180.28 127	432.65 304	357.29 251	383.06 267	290.24 x
7	140.35 100	136.94 98	132.23 94	125.41 89	175.25 125	49.84
8	115.35 100	108.33 94	98.23 85	109.65 95	123.41 107	25.18
9	209.94 100	231.50 113	183.82 90	191.53 93	231.41 113	47.68
10	141.00 100	195.61 139	211.59 150	196.23 139	192.47 136	70.59 x
13	170.5 100	180.88 106	217.00 127	221.25 130	252.62 148	82.12 x
14	188.53 100	205.00 109	237.77 126	237.65 126	303.76 161	115.23 x
Average	157.37 100	179.94 114	216.98 138	247.40 157	293.19 186	135.82 x

S_D (difference of averages for wells) = 29.5 D_{gr} (5) = 64.3

S_D (difference of 1 year averages) = 8.97 D_{gr} (5) = 19.55

Table 10-3. Average Cl Content (in mg/dm^3) and Dynamics of Percentage Increase as Compared to 1975

Number of well	1975	1976	1977	1978	1979	Maximum difference
1	14.87 100	18.36 123	20.29 136	45.54 306	60.6 407	45.73 x
2	12.36 100	14.78 120	38.0 307	48.65 394	49.41 400	37.05 x
3	18.60 100	15.86 85	24.23 130	42.88 230	42.65 229	26.79 x
5	11.98 100	12.11 101	17.47 146	27.65 231	31.41 262	19.43 x
6	16.94 100	19.64 116	49.38 291	54.18 320	49.35 291	37.24 x
7	17.26 100	17.69 102	18.12 105	19.76 114	22.75 132	5.49
8	12.44 100	14.25 114	14.71 118	16.47 132	14.12 113	4.03
9	17.49 100	18.86 108	25.41 145	27.47 157	26.94 154	9.98 x
10	18.15 100	18.55 102	21.59 119	27.53 152	22.23 122	9.38 x
13	14.56 100	17.05 117	20.25 139	27.69 190	29.0 199	14.44 x
14	19.14 100	18.47 97	29.35 153	31.0 162	35.0 183	16.53 x
Average	15.82 100	16.9 107	27.4 173	33.3 210	34.68 219	18.86 x

S_D (wells) = 3.92

S_D (average) = 1.18

$D_{gr}(5)$ = 8.54

$D_{gr}(5)$ = 2.58

Table 10-4. Average SO_4 Content (in mg/dm^3) and Dynamics of Percentage Increase as Compared to 1975

Number of well	1975	1976	1977	1978	1979	Maximum difference
1	66.97 100	68.92 103	89.87 134	145.46 217	228.6 341	161.63 x
2	66.32 100	78.09 118	79.69 120	168.65 254	186.53 281	120.21 x
3	59.38 100	51.21 86	64.02 108	119.47 201	157.29 265	106.01 x
5	44.56 100	42.70 96	50.47 113	82.0 184	95.76 215	53.06 x
6	34.17 100	39.14 114	99.17 290	94.53 277	125.94 369	91.77 x
7	23.41 100	15.36 66	12.77 54	16.41 70	46.06 197	33.29 x
8	35.76 100	22.24 62	25.4 71	29.82 83	29.0 81	13.52 x
9	68.96 100	65.73 95	39.41 57	52.47 76	86.12 125	46.71 x
10	34.74 100	51.09 147	38.64 111	54.65 157	62.12 179	27.38
13	51.72 100	60.07 116	70.11 135	73.37 142	91.94 178	40.22 x
14	54.63 100	59.52 109	68.61 126	72.82 133	109.88 225	55.25 x
Average	48.94 100	50.08 102	57.95 118	87.37 166	110.0 225	61.06 x

S_D (wells) = 12.9 $D_{gr}(5)$ = 28.13

S_D (average) = 3.9 $D_{gr}(5)$ = 8.5

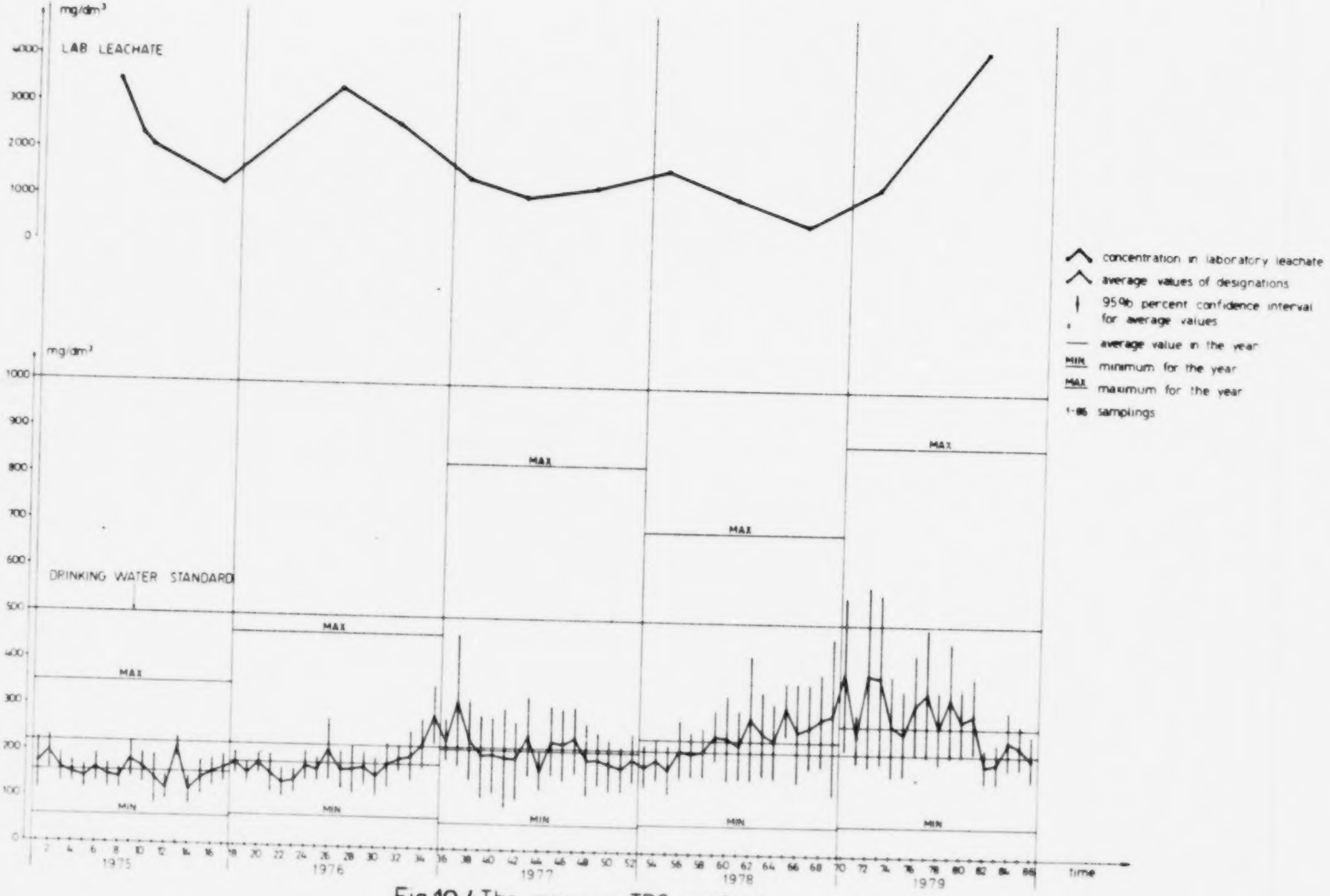


Fig.10-4.The average TDS content.

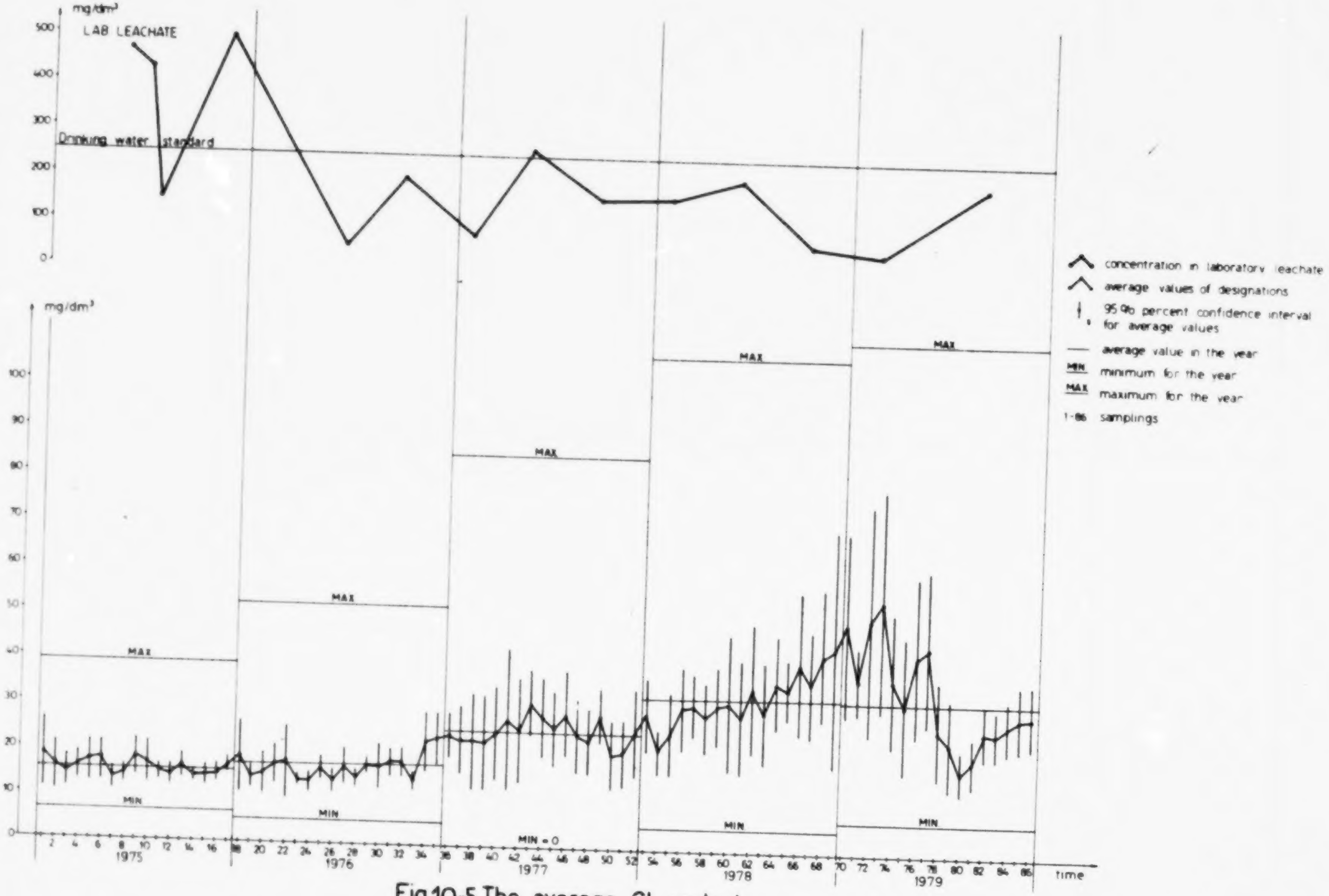


Fig.10-5.The average Cl content.

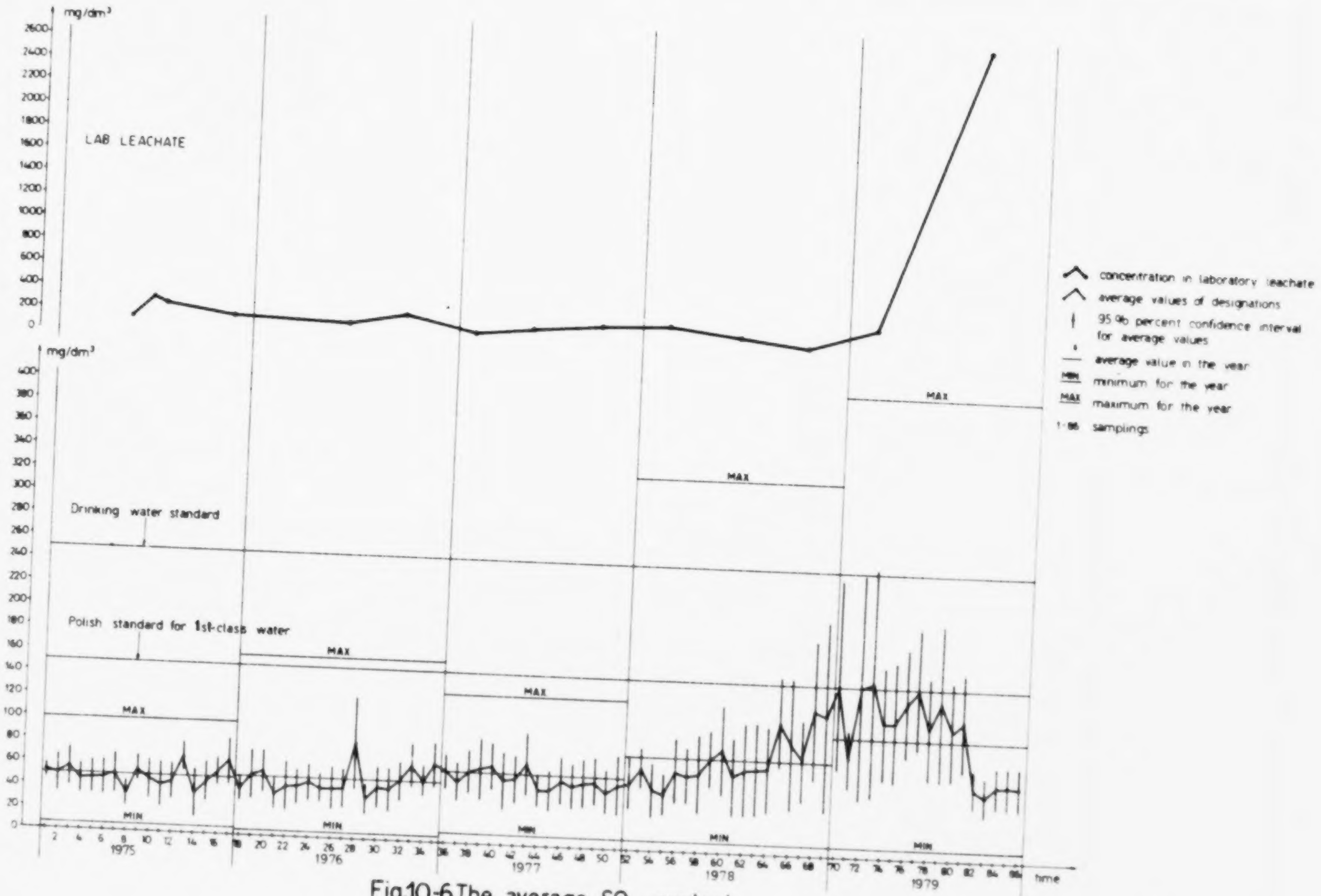


Fig.10-6.The average SO_4 content

APPENDICES

APPENDIX A

RESULTS OF GLASS COLUMN TESTS

Table A-1. The Results of Coal Refuse Laboratory Leachates Analyses

No.	Determination	Unit	Sample No. 1			Sample No. 2	
			S_1	S_2	S_3	S_1	S_2
1.	Smell		z2s	z2s	z2s	z1s	z2s
2.	Initial turbidity	mg/dm^3 O$_2$	-	5900	8600	20200	14800
3.	Turbidity after 3 centrifugings	- " -	700	260	-	-	-
4.	Conductivity	uS	1300	540	720	900	410
5.	pH		7,6	7,6	7,9	7,7	7,3
6.	Hardness	german grade	0,80	0,65	-	0,75	0,65
7.	Basicity	m val/um^3	1,9	1,9	-	1,95	2,25
8.	Acidity	m val/dm^3	0,22	0,16	-	0,20	0,10
9.	Oxygen demand	mg/dm^3 O$_2$	0,5	0,5	-	1,1	-
10.	Oxygen demand-organic	mg/dm^3 O$_2$	20,6	5,4	-	4,8	-
11.	Dry residue	mg/dm^3	-	-	5491	5799	10383
12.	TDS	mg/dm^3	705	960	1348	2005	1480
13.	Mineral dissolved substances	mg/dm^3	623	797	1078	1807	1319
14.	Volatile dissolved substances	mg/dm^3	82	163	270	198	161
15.	Cl	mg/dm^3	286	105	78	55	7
16.	SO$_4$	mg/dm^3	58	37	27	281	39
17.	^{N}NO$_3$	mg/dm^3	2,1	0,99	-	2,5	0,25
18.	^{N}NO$_2$	mg/dm^3	0,035	0,040	-	0,001	0,054
19.	^{N}NH$_4$	mg/dm^3	0,69	0,14		0,62	-
20.	N albumine	mg/dm^3	0,37	-	-	-	-
21.	PO$_4$	mg/dm^3	0,038	0,322	-	1,0	0,358
22.	CN free	mg/dm^3	0,007	0,008	-	0,016	0,015
23.	Phenols	mg/dm^3	0,400	0,560	-	0,280	0,005
24.	Fe total	mg/dm^3	0,530	1,525	-	2,225	0,775
25.	Fe^{++}	mg/dm^3	0,030	0,880	-	1,680	0,332
26.	Fe^{+++}	mg/dm^3	0,500	0,645	-	0,54	0,44
27.	Mn	mg/dm^3	0,100	0,100	-	0,165	0,290
28.	Ca	mg/dm^3	10	10	12	11	14
29.	Mg	mg/dm^3	0,330	0,780	1,40	1,55	1,45
30.	Na	mg/dm^3	217	137	164	216	117
31.	K	mg/dm^3	9	5	6	10	6
32.	Al	mg/dm^3	0,005	1,40	1,75	4,[illegible]	2,50
33.	Cr	mg/dm^3	0,010	0,006	-	0,012	0,009
34.	As	mg/dm^3	0,010	0,008	-	0,020	0,010
35.	Pb	mg/dm^3	0,016	0,500	-	0,042	0,026
36.	Cu	mg/dm^3	0,031	0,038	-	0,043	0,033
37.	Zn	mg/dm^3	0,175	29,25	-	3,750	0,145
38.	Hg	ug/dm^3	2,0	0,4		0,6	0,5
39.	Sr	mg/dm^3	0,020	0,040	-	0,035	0,050
40.	SiO$_2$	mg/dm^3	2,1	-	-	0,6	0,5
41.	B	mg/dm^3	0,410	0,023	-	0,019	0,012
42.	Mo	mg/dm^3	0,014	0,011	-	0,004	0,003
43.	Cd	mg/dm^3	0,002	0,023	-	0,005	0,001

Table A-2. The Results of Coal Refuse Laboratory Leachates Analyses

No.	Determination	Unit	Oct. 5, 1976 Leaching no. S_1	 S_2	 S_3
1.	Smell				
2.	Conductivity		z2s	z1s	z1s
3.	pH	uS /cm	1030	580	340
4.	Hardness	pH	8,05	8,0	7,3
5.	Basicity	grades	3,1	0,9	0,3
6.	Acidity	$mval/dm^3$	2,3	2,0	0,5
7.	T.D.S.	$mval/dm^3$	0,2	0,1	0,05
8.	T.D.Min.	mg/dm^3	1441	852	317
9.	T.D.V.	mg/dm^3	409	321	107
10.	C.C.D. inst.	mg/dm^3	1032	531	220
11.	C.O.D. org.	mg/dm^3 O_2	1,6	2,8	0,8
12.	Cl	mg/dm^3 O_2	3,8	2,8	1,6
13.	SO_4	mg/dm^3	148	44	8
14.	N_{NO_3}	mg/dm^3	198	10	5
15.	N_{NO_2}	mg/dm^3	3,02	0,30	0,61
16.	N_{NH_4}	mg/dm^3	0,016	0,015	0,006
17.	N alb.	mg/dm^3	0,12	0,21	0,16
18.	PO_4	mg/dm^3	0,50	0,57	0,52
19.	CN	mg/dm^3	0,046	0,096	0,162
20.	Phenols	mg/dm^3	0,001	0,001	0,001
21.	SiO_2	mg/dm^3	0,002	0,003	0,006
22.	Fe total	mg/dm^3	0,8	3,9	5,1
23.	Fe^{++}	mg/dm^3	0,35	14,90	20,40
24.	Fe^{+++}	mg/dm^3	-	-	-
25.	Mn	mg/dm^3	-	-	-
26.	Ca	mg/dm^3	0,065	0,400	0,375
27.	Mg	mg/dm^3	3,8	10,0	6,4
28.	Na	mg/dm^3	5,75	11,00	5,10
29.	K	mg/dm^3	262,5	38,5	56,0
30.	Al	mg/dm^3	12,8	5,7	8,5
31.	Cr	mg/dm^3	9,5	7,4	57,0
32.	As	mg/dm^3	0,009	0,013	0,014
33.	Pb	mg/dm^3	0,013	0,014	0,022
34.	Cu	mg/dm^3	0,040	0,053	0,100
35.	Zn	mg/dm^3	0,043	0,095	0,100
36.	Sr	mg/dm^3	0,079	0,205	0,090
37.	Cd	mg/dm^3	0,050	0,015	0,065
38.	Mo	mg/dm^3	0,013	0,051	0,007
39.	B	mg/dm^3	0,002	0,006	0,001
40.	Hg	mg/dm^3	0,080	0,045	0,025
		ug/dm^3	2,8	2,4	2,2

Table A-3. The Results of Coal Refuse Laboratory Leachates Analyses

Feb. 8, 1977

No.	Determination	Unit	Leaching no.		
			S_1	S_2	S_3
1.	Smell		z1s	z2s	z1s
2.	Conductivity	µS/cm	410	140	150
3.	pH	pH	8,2	8,25	8,7
4.	Herdness *	°grades	1,1	0,6	1,1
5.	Basicity	$mval/dm^3$	2,8	1,6	1,2
6.	Acidity	$mval/dm^3$	0,4	0,1	0,1
7.	T.D.S.	mg/dm^3	986	238	216
8.	T.D.Min.	mg/dm^3	780	136	116
9.	T.D.V.	mg/dm^3	206	102	100
10.	C.C.D. inst.	$mg/dm^3\ O_2$	2,2	1,0	0,9
11.	C.O.D. org.	$mg/dm^3\ O_2$	1,2	1,1	1,0
12.	Cl	mg/dm^3	54	10	15
13.	SO_4	mg/dm^3	43,5	24,0	23,4
14.	N_{NO_3}	mg/dm^3	0,37	0,08	0,06
15.	N_{NO_2}	mg/dm^3	0,054	0,013	0,009
16.	N_{NH_4}	mg/dm^3	1,14	0,24	0,005
17.	N alb.	mg/dm^3	0,05	0,13	0,85
18.	PO_4	mg/dm^3	0,068	0,380	0,800
19.	CN	mg/dm^3	0,0045	0,0028	0,0015
20.	Phenols	mg/dm^3	0,064	0,010	0,014
21.	SiO_2	mg/dm^3	4,3	3,1	3,1
22.	Fe total	mg/dm^3	16,300	7,500	2,090
23.	Fe^{++}	mg/dm^3	1,000	0,900	0,500
24.	Fe^{+++}	mg/dm^3	12,300	5,600	1,590
25.	Mn	mg/dm^3	0,305	0,155	0,055
26.	Ca	mg/dm^3	2,5	6,0	4,0
27.	Mg	mg/dm^3	4,45	3,40	1,31
28.	Na	mg/dm^3	159,0	8,3	4,2
29.	K	mg/dm^3	11,6	3,1	2,0
30.	Al	mg/dm^3	5,0	3,9	1,5
31.	Cr	mg/dm^3	0,014	0,015	0,006
32.	As	mg/dm^3	0,100	0,010	0,011
33.	Pb	mg/dm^3	0,105	0,056	0,076
34.	Cu	mg/dm^3	0,130	0,052	0,046
35.	Zn	mg/dm^3	0,380	0,140	0,115
36.	Sr	mg/dm^3	0,170	0,085	0,100
37.	Cd	mg/dm^3	0,0062	0,0033	0,0028
38.	Mo	mg/dm^3	0,006	0,0005	0,002
39.	B	mg/dm^3	0,725	0,300	0,170
40.	Hg	$\mu g/dm^3$	0,8	2,8	0,6

Table A-4. The Results of Coal Refuse Laboratory Leachates Analyses

May 27, 1977

No.	Determination	Unit	Leaching no.		
			S_1	S_2	S_3
1.	Smell		z1s	z2s	z1s
2.	Conductivity	µS/cm	810	450	170
3.	pH	pH	8,5	9,8	9,9
4.	Hardness	grades	6,0	1,6	1,2
5.	Basicity	mval/dm^3	2,4	3,2	2,1
6.	Acidity	mval/dm^3	0,8	0,7	0,4
7.	T.D.S.	mg/dm^3	690	234	130
8.	T.D.Min.	mg/dm^3	596	144	72
9.	T.D.V.	mg/dm^3	94	90	58
10.	C.C.D. Inst.	mg/dm^3 O_2	112	1,0	0,9
11.	C.O.D. org.	mg/dm^3 O_2	2,4	1,8	1,3
12.	Cl	mg/dm^3	180	52	32
13.	SO_4	mg/dm^3	108	16	10
14.	N_{NO_3}	mg/dm^3	2,16	0,30	0,07
15.	N_{NO_2}	mg/dm^3	0,036	0,025	0,016
16.	N_{NH_4}	mg/dm^3	0,47	0,28	0,22
17.	N alb.	mg/dm^3	0,08	0,11	0,13
18.	PO_4	mg/dm^3	0,012	0,006	0,018
19.	CN	mg/dm^3	0,025	0,007	0,006
20.	Phenols	mg/dm^3	0,003	0,005	0,005
21.	SiO_2	mg/dm^3	3,4	3,5	4,2
22.	Fe total	mg/dm^3	2,600	2,000	3,800
23.	Fe^{++}	mg/dm^3	0,065	0,030	0,100
24.	Fe^{+++}	mg/dm^3	2,535	1,970	3,700
25.	Mn	mg/dm^3	0,130	0,125	0,095
26.	Ca	mg/dm^3	2,3	1,6	1,9
27.	Mg	mg/dm^3	2,5	1,3	1,0
28.	Na	mg/dm^3	177,5	46,0	37,5
29.	K	mg/dm^3	6,7	3,1	2,2
30.	Al	mg/dm^3	4,35	2,95	3,40
31.	Cr	mg/dm^3	0,030	0,016	0,019
32.	As	mg/dm^3	0,045	0,038	0,050
33.	Pb	mg/dm^3	0,027	0,042	0,042
34.	Cu	mg/dm^3	0,045	0,030	0,020
35.	Zn	mg/dm^3	0,250	0,145	0,110
36.	Sr	mg/dm^3	0,050	0,050	0,030
37.	Cd	mg/dm^3	0,002	0,002	0,001
38.	Mo	mg/dm^3	0,012	0,009	0,003
39.	B	mg/dm^3	0,043	0,032	0,020
40.	Hg	µg/dm^3	4,0	6,0	0,9

Table A-5. The Results of Coal Refuse Laboratory Leachates Analyses

Sept. 27, 1977

No.	Determination	Unit	Leaching no.		
			S_1	S_2	S_3
1.	Smell		zle	zle	zle
2.	Conductivity	µS	850	600	350
3.	pH	pH	8,55	8,45	8,9
4.	Hardness	grades	0,3	0,5	0,8
5.	Basicity	mval/dm^3	2,0	2,8	3,2
6.	Acidity	mval/dm^3	-	-	-
7.	T.D.S.	mg/dm^3	738	270	262
8.	T.D.Min.	mg/dm^3	706	268	262
9.	T.D.V.	mg/dm^3	32	2	0
10.	C.C.D. inst.	mg/dm^3 O_2	1,2	1,1	1,1
11.	C.O.D. org.	mg/dm^3 O_2	2,8	2,6	2,8
12.	Cl	mg/dm^3	120	26	14
13.	SO_4	mg/dm^3	87	48	46
14.	N_{NO_3}	mg/dm^3	2,42	0,54	0,52
15.	N_{NO_2}	mg/dm^3	0,174	0,046	0,035
16.	N_{NH_4}	mg/dm^3	1,87	0,09	2,5
17.	N alb.	mg/dm^3	0,08	0,16	0,45
18.	PO_4	mg/dm^3	0,64	1,28	1,24
19.	CN	mg/dm^3	0,031	0,029	0,006
20.	Phenols	mg/dm^3	0,005	0,003	0,002
21.	SiO_2	mg/dm^3	7,0	6,0	6,8
22.	Fe total	mg/dm^3	6,00	8,90	11,20
23.	Fe^{+++}	mg/dm^3	0,95	4,30	6,35
24.	Fe^{++}	mg/dm^3	5,05	4,60	4,85
25.	Mn	mg/dm^3	0,200	0,285	0,275
26.	Ca	mg/dm^3	2,6	2,0	2,6
27.	Mg	mg/dm^3	0,10	0,17	0,15
28.	Na	mg/dm^3	23,5	11,0	10,0
29.	K	mg/dm^3	7,2	5,0	4,7
30.	Al	mg/dm^3	3,20	5,25	7,75
31.	Cr	mg/dm^3	0,007	<0,002	0,002
32.	As	mg/dm^3	0,045	0,050	0,022
33.	Pb	mg/dm^3	0,050	0,100	0,059
34.	Cu	mg/dm^3	0,018	0,018	0,020
35.	Zn	mg/dm^3	0,445	0,385	0,260
36.	Hg	µg/dm^3	3,0	2,0	1,5
37.	Sr	mg/dm^3	0,080	0,060	0,060
38.	Cd	mg/dm^3	0,005	0,003	0,002
39.	Mo	mg/dm^3	0,013	0,225	0,140
40.	B	mg/dm^3	0,430	0,225	0,140

Table 1

Table A-6. The Results of Coal Refuse Laboratory Leachates Analyses

Feb. 2, 1978

No.	Determination	Unit	Leaching no.		
			S_1	S_2	S_3
1.	Smell		zle	zle	zle
2.	Conductivity	µS	1080	540	400
3.	pH	pH	9,0	9,6	9,9
4.	Hardness	grades	1,4	0,8	0,8
5.	Basicity	mval/ dm^3	3,6	3,4	2,0
6.	Acidity	mval/dm^3	0,1	0,1	0,1
7.	T.D.S.	mg/dm^3	850	488	325
8.	T.D.Min.	mg/dm^3	622	316	208
9.	T.D.V.	mg/dm^3	228	172	117
10.	C.C.D. inst.	mg/dm^3 O_2	0,5	0,4	0.4
11.	C.O.D. org.	mg/dm^3 O_2	2,5	2,0	1,9
12.	Cl	mg/dm^3	92	38	36
13.	SO_4	mg/ dm^3	141	44	15
14.	N_{NO_3}	mg/dm^3	5,34	0,99	0,36
15.	N_{NO_2}	mg/ dm^3	0,124	0,096	0,120
16.	N_{NH_4}	mg/dm^3	1,20	1,87	0,48
17.	N alb.	mg/ dm^3	0,12	0,15	0,15
18.	PO_4	mg/dm^3	0,034	0,022	0,012
19.	CN	mg/ dm^3	-	-	-
20.	Phenols	mg/ dm^3	0,005	0,002	0,005
21.	SiO_2	mg/ dm^3	2,4	1,3	2,5
22.	Fe total	mg/dm^3	5,90	11,00	10,00
23.	Fe^{++}	mg/dm^3	1,15	1,65	0,16
24.	Fe^{+++}	mg/ dm^3	4,75	9,35	9,84
25.	Mn	mg/ dm^3	0,135	0,305	0,325
26.	Ca	mg/dm^3	14,2	8,3	8,3
27.	Mg	mg/dm^3	6,0	4,8	2,8
28.	Na	mg/dm^3	187	88	48
29.	K	mg/ dm^3	9,8	9,2	8,3
30.	Al	mg/ dm^3	8,7	18,0	11,8
31.	Cr	mg/dm^3	0,032	0,024	0,033
32.	As	mg/dm^3	0,050	0,050	0,021
33.	Pb	mg/dm^3	0,040	0,080	0,075
34.	Cu	mg/ dm^3	0,065	0,110	0,100
35.	Zn	mg/dm^3	0,310	0,280	0,260
36.	Sr	mg/dm^3	0,097	0,168	0,172
37.	Cd	mg/ dm^3	0,003	0,005	0,003
38.	Mo	mg/dm^3	0,015	0,010	0,004
39.	B	mg/dm^3	1,67	1,32	0,61
40.	Hg	µg/dm^3	5,0	2,5	2,5

Table 2

Table A-7. The Results of Coal Refuse Laboratory Leachates Analyses

Jun. 7, 1978

No.	Determination	Unit	Leaching no.		
			S_1	S_2	S_3
1.	Smell		z1e	z1e	z1e
2.	Conductivity	µS	810	400	200
3.	pH	pH	9,2	9,6	9,6
4.	Hardness	grades	0,6	2,0	2,4
5.	Basicity	mval/dm^3	4,6	1,2	1,1
6.	Acidity	mval/dm^3	-	-	-
7.	T.D.S.	mg/dm^3	650	302	170
8.	T.D.Min.	mg/dm^3	470	218	130
9.	T.D.V.	mg/dm^3	180	84	40
10.	C.C.D. inst.	mg/dm^3 O_2	0,2	0,2	0,1
11.	C.O.D. org.	mg/dm^3 O_2	2,2	2,2	1,8
12.	Cl	mg/dm^3	85	87	36
13.	SO_4	mg/dm^3	91	20	16
14.	N_{NO_3}	mg/dm^3	0,200	0,176	0,164
15.	N_{NO_2}	mg/dm^3	4,78	0,66	0,08
16.	N_{NH_4}	mg/dm^3	0,63	0,48	0,28
17.	N alb.	mg/dm^3	0,15	0,13	0,12
18.	PO_4	mg/dm^3	0,036	0,010	0,008
19.	CN	mg/dm^3	0,004	0,003	0,003
20.	Phenols	mg/dm^3	0,003	0,003	0,005
21.	SiO_2	mg/dm^3	1,9	1,8	2,0
22.	Fe total	mg/dm^3	26,20	4,50	2,70
23.	Fe^{++}	mg/dm^3	0,02	0,06	0,12
24.	Fe^{+++}	mg/dm^3	26,18	4,44	2,58
25.	Mn	mg/dm^3	0,095	0,087	0,070
26.	Ca	mg/dm^3	5,7	7,1	11,4
27.	Mg	mg/dm^3	3,2	6,8	6,4
28.	Na	mg/dm^3	186,0	58,2	41,3
29.	K	mg/dm^3	8,7	4,7	3,5
30.	Al	mg/dm^3	2,8	2,8	2,2
31.	Cr	mg/dm^3	0,013	0,009	0,010
32.	As	mg/dm^3	0,074	0,016	0,036
33.	Pb	mg/dm^3	0,015	0,025	0,050
34.	Cu	mg/dm^3	0,040	0,025	0,010
35.	Zn	mg/dm^3	0,500	0,840	0,650
36.	Sr	mg/dm^3	0,200	0,105	0,060
37.	Cd	mg/dm^3	0,003	0,002	0,002
38.	Mo	mg/dm^3	-	-	-
39.	B	mg/dm^3	0,485	0,445	0,340
40.	Hg	µg/dm^3	4,0	2,0	1,7

Table 3

Table A-8. The Results of Coal Refuse Laboratory Leachates Analyses

Oct. 11, 1978

No.	Determination	Unit	Leaching no.		
			S_1	S_2	S_3
1.	Smell		z1S	z1S	z1S
2.	Conductivity	µS	275	171	54
3.	pH	pH	8,1	8,5	7,5
4.	Hardness	grades	1,2	0,6	0,4
5.	Basicity	$mval/dm^3$	2,8	2,25	1,7
6.	Acidity	$mval/dm^3$	-	-	-
7.	T.D.S.	mg/dm^3	288	154	106
8.	T.D.Min.	mg/dm^3	204	96	82
9.	T.D.V.	mg/dm^3	84	58	24
10.	C.C.D. inst.	$mg/dm^3\ O_2$	2,4	2,0	1,6
11.	C.O.D. org.	$mg/dm^3\ O_2$	-	-	-
12.	Cl	mg/dm^3	49	8	7
13.	SO_4	mg/dm^3	33	9	8
14.	N_{NO_3}	mg/dm^3	0,007	0,013	0,007
15.	N_{NO_2}	mg/dm^3	0,45	0,07	0,05
16.	N_{NH_4}	mg/dm^3	0,10	0,15	0,09
17.	N alb.	mg/dm^3	0,18	0,20	0,10
18.	PO_4	mg/dm^3	1,021	0,310	0,500
19.	CN	mg/dm^3	0,019	0,006	0,003
20.	Phenols	mg/dm^3	0,003	0,003	0,003
21.	SiO_2	mg/dm^3	1,4	2,0	3,1
22.	Fe total	mg/dm^3	1,19	1,49	0,94
23.	Fe^{++}	mg/dm^3	0,05	0,30	0,19
24.	Fe^{+++}	mg/dm^3	1,14	1,19	0,75
25.	Mn	mg/dm^3	0,067	0,043	0,022
26.	Ca	mg/dm^3	8,6	3,6	2,1
27.	Mg	mg/dm^3	0	1,0	1,0
28.	Na	mg/dm^3	65,0	20,5	14,5
29.	K	mg/dm^3	2,8	0,8	0,5
30.	Al	mg/dm^3	3,25	2,75	5,00
31.	Cr	mg/dm^3	0,008	0,017	0,005
32.	As	mg/dm^3	0,002	0,005	0,001
33.	Pb	mg/dm^3	0,028	0,003	0,003
34.	Cu	mg/dm^3	0,025	0,008	0,003
35.	Zn	mg/dm^3	0,250	0,065	0,045
36.	Sr	mg/dm^3	0,017	0,010	0,010
37.	Cd	mg/dm^3	0,006	0,002	0,001
38.	Mo	mg/dm^3	0,002	0,001	0,000
39.	B	mg/dm^3	0,260	0,150	0,130
40.	Hg	$µg/dm^3$	1,5	1,0	0,5

Table A-9. The Results of Coal Refuse Laboratory Leachates Analyses

Mar. 2, 1979

No.	Determination	Unit	Leaching no.		
			S_1	S_2	S_3
1.	Smell		z3s	z2s	z2s
2.	Conductivity	µS	720	300	240
3.	pH	pH	7,65	8,2	8,55
4.	Hardness	grades	2,5	1,5	1,5
5.	Basicity	mval/dm^3	4,8	2,9	1,9
6.	Acidity	mval/dm^3	0,2	0,15	0,15
7.	T.D.S.	mg/dm^3	726	384	262
8.	T.D.Mn.	mg/dm^3	642	324	240
9.	T.D.V.	mg/dm^3	84	60	12
10.	C.C.D. inst.	mg/dm^3 O_2	0,3	0,4	0,4
11.	C.O.D. org.	mg/dm^3 O_2	5,6	5,8	5,8
12.	Cl	mg/dm^3	30	11	10
13.	SO_4	mg/dm^3	164	33	33
14.	N_{NO_3}	mg/dm^3	0,021	0,019	0,010
15.	N_{NO_2}	mg/dm^3	3,96	1,20	0,24
16.	N_{NH_4}	mg/dm^3	0,91	0,71	0,74
17.	N alb.	mg/dm^3	0,15	0,16	0,11
18.	PO_4	mg/dm^3	0,008	0,016	0,038
19.	CN	mg/dm^3	0,026	0,018	0,018
20.	Phenols	mg/dm^3	0,007	0,005	0,003
21.	SiO_2	mg/dm^3	1,5	1,6	2,2
22.	Fe total	mg/dm^3	48,70	25,00	2,15
23.	Fe^{++}	mg/dm^3	2,45	0,60	0,26
24.	Fe^{+++}	mg/dm^3	46,25	24,40	1,89
25.	Mn	mg/dm^3	2,550	0,315	0,130
26.	Ca	mg/dm^3	3,5	5,6	5,6
27.	Mg	mg/dm^3	0,8	1,0	1,2
28.	Na	mg/dm^3	180,5	58,6	40,2
29.	K	mg/dm^3	24,1	5,3	4,5
30.	Al	mg/dm^3	16,0	5,0	4,4
31.	Cr	mg/dm^3	0,021	0,002	0,002
32.	As	mg/dm^3	0,021	0,027	0,016
33.	Pb	mg/dm^3	0,147	0,069	0,055
34.	Cu	mg/dm^3	0,730	0,115	0,080
35.	Zn	mg/dm^3	2,350	0,470	0,285
36.	Sr	mg/dm^3	0,190	0,030	0,020
37.	Cd	mg/dm^3	0,017	0,003	0,003
38.	Mo	mg/dm^3	0,004	0,004	0,003
39.	B	mg/dm^3	0,495	0,320	0,270
40.	Hg	mg/dm^3	0,2	0,2	0,2

Table A-10. The Results of Coal Refuse Laboratory Leachates Analyses

Aug. 21, 1979

No.	Determination	Unit	Leaching no.		
			S_1	S_2	S_3
1.	Smell		z1S	z1S	z1S
2.	Conductivity	µS	8100	1150	430
3.	pH	pH	8,35	8,8	9,05
4.	Hardness	grades	76,6	25,5	10,8
5.	Basicity	$mval/dm^3$	1,9	1,5	1,3
6.	Acidity	$mval/dm^3$	0,3	0,3	0,3
7.	T.D.S.	mg/dm^3	3210	840	302
8.	T.D.Min.	mg/dm^3	2872	756	272
9.	T.D.V.	mg/dm^3	338	84	30
10.	C.C.D. inst.	mg/dm^3 O_2	3,1	1,8	1,7
11.	C.O.D. org.	mg/dm^3 O_2	-	-	-
12.	Cl	mg/dm^3	183	14	5
13.	SO_4	mg/dm^3	1974	399	130
14.	N_{NO_3}	mg/dm^3	0,013	0,002	0,002
15.	N_{NO_2}	mg/dm^3	2,75	0,12	0,15
16.	N_{NH_4}	mg/dm^3	0,21	0,09	0,02
17.	N alb.	mg/dm^3	0,28	0,18	0,16
18.	PO_4	mg/dm^3	0,640	0,420	0,360
19.	CN	mg/dm^3	0,0017	0,0035	0,0050
20.	Phenols	mg/dm^3	0,002	0,003	0,003
21.	SiO_2	mg/dm^3	7,0	6,8	6,0
22.	Fe total	mg/dm^3	0,045	0,050	0,017
23.	Fe^{++}	mg/dm^3	0,04	0,005	0,005
24.	Fe^{+++}	mg/dm^3	0,005	0,050	0,017
25.	Mn	mg/dm^3	0,023	0,005	0,007
26.	Ca	mg/dm^3	233,9	79,3	42,7
27.	Mg	mg/dm^3	190,0	45,2	14,4
28.	Na	mg/dm^3	290,0	29,5	7,0
29.	K	mg/dm^3	245,0	44,0	28,0
30.	Al	mg/dm^3	0,40	0,15	0,15
31.	Cr	mg/dm^3	0,021	0,008	0,007
32.	As	mg/dm^3	0,035	0,010	0,005
33.	Pb	mg/dm^3	0,085	0,025	0,010
34.	Cu	mg/dm^3	0,010	0,003	0,006
35.	Zn	mg/dm^3	0,300	0,105	0,035
36.	Sr	mg/dm^3	1,600	0,260	0,190
37.	Cd	mg/dm^3	0,015	0,004	0,003
38.	Mo	mg/dm^3	0,015	0,004	0,003
39.	B	mg/dm^3	0,670	0,450	0,200
40.	Hg	$\mu g/dm^3$	3,6	1,5	0,8

APPENDIX B

COMPUTER PRINT-OUTS OF STATISTICAL COMPUTATIONS

```
POLLUTING FACTOR:  TDS          UNIT:  MG/L

MONITORING WELLS:     1  2  3  5  6  7  8  9 10 13 14
LIMITING DATES:     10 12 74    20 12 79

NUMBER OF WELLS:  11     NUMBER OF MEASURMENTS:  72

------------------------------------------------------------------------------------------
            NUMBER OF
VARIATION    DEGREES      SUM OF SQUARES            MEAN SQUARE              F EMPIRICAL
            OF FREEDOM
------------------------------------------------------------------------------------------
WELLS              10   .230349070458984D 07   .230349070457464E 06   .311186102451728E 02

MEASURMENTS        71   .309797472753906D 07   .436334468665080E 05   .589458522235446E 01

DEVIATION         710   .525562802246094D 07   .740229298937151E 04

TOTAL             791   .106570934545898D 08
------------------------------------------------------------------------------------------


STANDARD DEVIATION OF TOTAL MEAN                    3.05718
STANDARD DEVIATION OF MEAN FOR WELLS               10.13951
STANDARD DEVIATION OF MEAN FOR MEASURMENTS         25.94100

STANDARD MEASURMENT DIFFERENCE ERROR                  121.67410
STANDARD MEAN DIFFERENCE ERROR FOR WELLS               14.33943
STANDARD MEAN DIFFERENCE ERROR FOR MEASURMENTS         36.68612
```

```
POLLUTING FACTOR:  TDS          UNIT:  MG/L

------------------------------------------------------------------------------------------------------------------------------
ORD. WELL
NO.   NO.    MEAN     -------------------------------------EMPIRICAL DIFFERENCES OF K MEANS-----------------------------------
                         K=2       K=3       K=4       K=5       K=6       K=7       K=8       K=9       K=10      K=11
------------------------------------------------------------------------------------------------------------------------------
  1    8    110.4028   31.1250   68.0139   78.5278   95.3472   96.4028  123.5139  134.2222  157.2500  170.8611  176.1389
  2    7    141.5278   36.8889   47.4028   64.2222   65.2778   92.3889  103.0972  126.1250  139.7361  145.0139
  3    5    178.4167   10.5139   27.3333   28.3889   55.5000   66.2083   89.2361  102.8472  108.1250
  4   10    188.9306   16.8194   17.8750   44.9861   55.6944   78.7222   92.3333   97.6111
  5    9    205.7500    1.0556   28.1667   38.8750   61.9028   75.5139   80.7917
  6   13    206.8056   27.1111   37.8194   60.8472   74.4583   79.7361
  7   14    233.9167   10.7083   33.7361   47.3472   52.6250
  8    3    244.6250   23.0278   36.6389   41.9167
  9    1    267.6528   13.6111   18.8889
 10    2    281.2639    5.2778
 11    6    286.5417
------------------------------------------------------------------------------------------------------------------------------
LIMIT DIFFERENCES      28.1053   29.5392   30.5430   31.2600   31.8335   32.4071   32.8373   33.1241   33.4109   33.6260
------------------------------------------------------------------------------------------------------------------------------
```

```
POLLUTING FACTOR:  CL-          UNIT: ' MG/L

MONITORING WELLS:     1  2  3  5  6  7  8  9 10 13 14
LIMITING DATES:     10 12 74     20 12 79

NUMBER OF WELLS:  11      NUMBER OF MEASURMENTS:  72

------------------------------------------------------------------------------------------
              NUMBER OF
VARIATION      DEGREES      SUM OF SQUARES           MEAN SQUARE              F EMPIRICAL
             OF FREEDOM
------------------------------------------------------------------------------------------
WELLS               10   .282030751245287D 05   .282030751243169E 04   .216158958973792E 02

MEASURMENTS         71   .716712698822021D 05   .100945450537636E 04   .773683841392625E 01

DEVIATION          710   .926363794195387D 05   .130473773829635E 03

TOTAL              791   .192510724426270D 06
------------------------------------------------------------------------------------------


STANDARD DEVIATION OF TOTAL MEAN                     0.40588
STANDARD DEVIATION OF MEAN FOR WELLS                 1.34616
STANDARD DEVIATION OF MEAN FOR MEASURMENTS           3.44402

STANDARD MEASURMENT DIFFERENCE ERROR                    16.15387
STANDARD MEAN DIFFERENCE ERROR FOR WELLS                 1.90375
STANDARD MEAN DIFFERENCE ERROR FOR MEASURMENTS           4.87058
```

POLLUTING FACTOR: CL-   UNIT: MG/L

ORD. NO.	WELL NO.	MEAN	EMPIRICAL DIFFERENCES OF K MEANS									
			K=2	K=3	K=4	K=5	K=6	K=7	K=8	K=9	K=10	K=11
1	8	14.7014	4.1944	4.2569	6.5625	6.6944	7.7847	11.0833	13.1042	14.9653	15.9028	21.3403
2	5	18.8958	0.0625	2.3681	2.5000	3.5903	6.8889	8.9097	10.7708	11.7083	17.1458	
3	7	18.9583	2.3056	2.4375	3.5278	6.8264	8.8472	10.7083	11.6458	17.0833		
4	10	21.2639	0.1319	1.2222	4.5208	6.5417	8.4028	9.3403	14.7778			
5	13	21.3958	1.0903	4.3889	6.4097	8.2708	9.2083	14.6458				
6	9	22.4861	3.2986	5.3194	7.1806	8.1181	13.5556					
7	14	25.7847	2.0208	3.8819	4.8194	10.2569						
8	3	27.8056	1.8611	2.7986	8.2361							
9	1	29.6667	0.9375	6.3750								
10	2	30.6042	5.4375									
11	6	36.0417										
LIMIT DIFFERENCES			3.7314	3.9217	4.0550	4.1502	4.2263	4.3025	4.3596	4.3977	4.4357	4.4643

```
POLLUTING FACTOR:  SO4=        UNIT:  MG/L

MONITORING WELLS:     1  2  3  5  6  7  8  9 10 13 14
LIMITING DATES:    10 12 74    20 12 79

NUMBER OF WELLS:  11     NUMBER OF MEASURMENTS:  72

------------------------------------------------------------------------------------------------
VARIATION   NUMBER OF
             DEGREES        SUM OF SQUARES           MEAN SQUARE             F EMPIRICAL
            OF FREEDOM
------------------------------------------------------------------------------------------------
WELLS             10   .582095216967265D 06   .582095216965683E 05   .411393925161078E 02

MEASURMENTS       71   .690834879882812D 06   .973006873071113E 04   .687669482681627E 01

DEVIATION        710   .100460307935842D 07   .141493391458666E 04

TOTAL            791   .227753317620850D 07
------------------------------------------------------------------------------------------------

STANDARD DEVIATION OF TOTAL MEAN                      1.33661
STANDARD DEVIATION OF MEAN FOR WELLS                  4.43304
STANDARD DEVIATION OF MEAN FOR MEASURMENTS           11.34153

STANDARD MEASURMENT DIFFERENCE ERROR                    53.19650
STANDARD MEAN DIFFERENCE ERROR FOR WELLS                 6.26927
STANDARD MEAN DIFFERENCE ERROR FOR MEASURMENTS          16.03935
```

```
POLLUTING FACTOR:  SO4=          UNIT:  MG/L

---------------------------------------------------------------------------------------------------------------------------
ORD. WELL
NO.   NO.      MEAN   -------------------------------------EMPIRICAL DIFFERENCES OF K MEANS-------------------------------
                           K=2       K=3       K=4       K=5       K=6       K=7       K=8       K=9      K=10      K=11
---------------------------------------------------------------------------------------------------------------------------
 1     7     23.3167     5.1069   25.0750   36.1819   37.4597   45.8292   50.3569   52.9597   61.3014   87.1153   87.5181
 2     8     28.4236    19.9681   31.0750   32.3528   40.7222   45.2500   47.8528   56.1944   82.0083   82.4111
 3    10     48.3917    11.1069   12.3847   20.7542   25.2819   27.8847   36.2264   62.0403   62.4431
 4     5     59.4986     1.2778    9.6472   14.1750   16.7778   25.1194   50.9333   51.3361
 5     9     60.7764     8.3694   12.8972   15.5000   23.8417   49.6556   50.0583
 6    13     69.1458     4.5278    7.1306   15.4722   41.2861   41.6889
 7    14     73.6736     2.6028   10.9444   36.7583   37.1611
 8     6     76.2764     8.3417   34.1556   34.5583
 9     3     84.6181    25.8139   26.2167
10     1    110.4319     0.4028
11     2    110.8347
---------------------------------------------------------------------------------------------------------------------------
LIMIT DIFFERENCES       12.2878   12.9147   13.3535   13.6670   13.9178   14.1685   14.3566   14.4820   14.6074   14.7014
---------------------------------------------------------------------------------------------------------------------------
```

```
BOI-PWB
DATE  15/04/80

STATISTICAL  ANALYSIS  OF  MEASURMENTS  FROM     1  12  74  UNTIL    30  12  79
POLLUTING  FACTOR   -  TDS     MG/L
-------------------------------------------------------------------------------------------
.WELLS   NUMB.       MEAN         STANDARD        CONFIDENCE       MINIMUM       MAXIMUM
         MEASUR                   DEVIATION       HALFINTERVAL      VALUE          VALUE
  NO.    MENTS                                     FOR MEAN
  I      N(I)        X(I)           S(I)             D(I)           XMIN          XMAX
-------------------------------------------------------------------------------------------
   1      78       278.4487       167.9254         37.9199        100.0000      884.0000
   2      84       293.5833       134.4857         29.2347        123.0000      754.0000
   3      86       256.2674       137.2331         29.4731         97.0000      878.0000
   5      86       190.8837        77.5948         16.6648         80.0000      538.0000
   6      86       297.7558       146.6220         31.4895         64.0000      696.0000
   7      85       141.5882        71.8862         15.5319         57.0000      354.0000
   8      86       110.9651        42.3663          9.0989         58.0000      261.0000
   9      86       208.9070        76.2940         16.3854         82.0000      500.0000
  10      86       187.4767        82.6974         17.7607        110.0000      832.0000
  13      81       208.1111        67.0091         14.8413         90.0000      470.0000
  14      85       234:5412        97.7231         21.1143         61.0000      772.0000
-------------------------------------------------------------------------------------------
SUM      929       218.4090       120.7798          7.7668
-------------------------------------------------------------------------------------------
MAXIMUM  AVERAGE  POLLUTION               -      297.755814    WELLS     6
MINIMUM  AVERAGE  POLLUTION               -      110.965116    WELLS     8
MAXIMUM  VALUE  OF  MEAN  DIFFERENCE      -      186.790698
MAXIMUM  VARIANCE                         -    28198.925907    WELLS     1
MINIMUM  VARIANCE                         -     1794.904651    WELLS     8
VALUE  OF  F-TEST                         -       15.710543
```

```
BOI-PWB
DATE  15/04/80

STATISTICAL  ANALYSIS  OF  MEASURMENTS  FROM     1  12  74  UNTIL    30  12  79
POLLUTING  FACTOR   -  TDS      MG/L

EMPIRICAL  DISTRIBUTIONS
N(I) - NUMBER  OF  MEASURMENTS  IN  THE  I-TH  CLASS
F'(I)- FREQUENCY  IN  I-TH  CLASS
F(I) - CUMULATED  FREQUENCY  IN  I-TH  CLASS
------------------------------------------------------------------------------------------------------------------
WELLS
                  ------------------------ C L A S S    I N T E R V A L S ----------------------------------------
 NO.
                   UNDER     FR  100.   FR  200.   FR  300.   FR  400.   FR  500.   FR  600.   FR  700.      OVER
                    100.     TO  200.   TO  300.   TO  400.   TO  500.   TO  600.   TO  700.   TO  800.      800.
------------------------------------------------------------------------------------------------------------------
   1   N(I)           0         34         22          9          5          3          2          0          3
       F'(I)    0.00000    0.43590    0.28205    0.11538    0.06410    0.03846    0.02564    0.00000    0.03846
       F(I)     0.00000    0.43590    0.71795    0.83333    0.89744    0.93590    0.96154    0.96154    1.00000
------------------------------------------------------------------------------------------------------------------
   2   N(I)           0         20         36         13          7          4          3          1          0
       F'(I)    0.00000    0.23810    0.42857    0.15476    0.08333    0.04762    0.03571    0.01190    0.00000
       F(I)     0.00000    0.23810    0.66667    0.82143    0.90476    0.95238    0.98810    1.00000    1.00000
------------------------------------------------------------------------------------------------------------------
   3   N(I)           2         30         33         12          4          2          1          1          1
       F'(I)    0.02326    0.34884    0.38372    0.13953    0.04651    0.02326    0.01163    0.01163    0.01163
       F(I)     0.02326    0.37209    0.75581    0.89535    0.94186    0.96512    0.97674    0.98837    1.00000
------------------------------------------------------------------------------------------------------------------
   5   N(I)           5         53         22          4          1          1          0          0          0
       F'(I)    0.05814    0.61628    0.25581    0.04651    0.01163    0.01163    0.00000    0.00000    0.00000
       F(I)     0.05814    0.67442    0.93023    0.97674    0.98837    1.00000    1.00000    1.00000    1.00000
------------------------------------------------------------------------------------------------------------------
   6   N(I)           6         24          9         27         10          8          2          0          0
       F'(I)    0.06977    0.27907    0.10465    0.31395    0.11628    0.09302    0.02326    0.00000    0.00000
       F(I)     0.06977    0.34884    0.45349    0.76744    0.88372    0.97674    1.00000    1.00000    1.00000
------------------------------------------------------------------------------------------------------------------
   7   N(I)          24         44         12          5          0          0          0          0          0
       F'(I)    0.28235    0.51765    0.14118    0.05882    0.00000    0.00000    0.00000    0.00000    0.00000
       F(I)     0.28235    0.80000    0.94118    1.00000    1.00000    1.00000    1.00000    1.00000    1.00000
------------------------------------------------------------------------------------------------------------------
   8   N(I)          38         44          4          0          0          0          0          0          0
       F'(I)    0.44186    0.51163    0.04651    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
       F(I)     0.44186    0.95349    1.00000    1.00000    1.00000    1.00000    1.00000    1.00000    1.00000
------------------------------------------------------------------------------------------------------------------
   9   N(I)           1         44         32          5          3          1          0          0          0
       F'(I)    0.01163    0.51163    0.37209    0.05814    0.03488    0.01163    0.00000    0.00000    0.00000
       F(I)     0.01163    0.52326    0.89535    0.95349    0.98837    1.00000    1.00000    1.00000    1.00000
------------------------------------------------------------------------------------------------------------------
  10   N(I)           0         66         17          2          0          0          0          0          1
       F'(I)    0.00000    0.76744    0.19767    0.02326    0.00000    0.00000    0.00000    0.00000    0.01163
       F(I)     0.00000    0.76744    0.96512    0.98837    0.98837    0.98837    0.98837    0.98837    1.00000
------------------------------------------------------------------------------------------------------------------
  13   N(I)           1         39         32          7          2          0          0          0          0
       F'(I)    0.01235    0.48148    0.39506    0.08642    0.02469    0.00000    0.00000    0.00000    0.00000
       F(I)     0.01235    0.49383    0.88889    0.97531    1.00000    1.00000    1.00000    1.00000    1.00000
------------------------------------------------------------------------------------------------------------------
  14   N(I)           2         30         38         11          3          0          0          1          0
       F'(I)    0.02353    0.35294    0.44706    0.12941    0.03529    0.00000    0.00000    0.01176    0.00000
       F(I)     0.02353    0.37647    0.82353    0.95294    0.98824    0.98824    0.98824    1.00000    1.00000
------------------------------------------------------------------------------------------------------------------
 SUM   N(I)          79        428        257         95         35         19          8          3          5
       F'(I)    0.08504    0.46071    0.27664    0.10226    0.03767    0.02045    0.00861    0.00323    0.00538
       F(I)     0.08504    0.54575    0.82239    0.92465    0.96233    0.98278    0.99139    0.99462    1.00000
------------------------------------------------------------------------------------------------------------------
```

BOI-PWB
DATE 15/04/80

STATISTICAL ANALYSIS OF MEASURMENTS FROM 1 12 74 UNTIL 30 12 79
POLLUTING FACTOR - TDS MG/L

MEASUR MENTS NO.	DATE OF MEASURMENTS	NUMBER WELLS	MEAN	STANDARD DEVIATION	95 % CONFIDENCE INTERVAL FOR MEAN	
					LOWER LIMIT	UPPER LIMIT
1	10 12 74	9	171.5556	71.7027	116.4401	226.6710
2	14 1 75	10	197.0000	48.8353	162.0677	231.9323
3	3 2 75	11	161.4545	45.5903	130.8285	192.0806
4	18 3 75	11	154.7273	35.4967	130.8817	178.5728
5	8 4 75	11	143.2727	38.1237	117.6625	168.8830
6	29 4 75	11	163.3636	44.0619	133.7643	192.9630
7	22 5 75	11	146.1818	37.9416	120.6939	171.6697
8	12 6 75	11	139.6364	31.2227	118.6620	160.6107
9	3 7 75	11	181.1818	57.9462	142.2554	220.1082
10	23 7 75	11	165.3636	47.5085	133.4490	197.2783
11	12 8 75	11	140.1818	79.3093	86.9044	193.4592
12	1 9 75	11	122.0000	39.9500	95.1629	148.8371
13	24 9 75	11	212.0909	29.9582	191.9660	232.2158
14	14 10 75	11	117.1818	45.8428	86.3861	147.9775
15	4 11 75	11	143.8182	53.8030	107.6751	179.9613
16	25 11 75	11	156.8182	40.0495	129.9142	183.7221
17	16 12 75	11	165.6364	41.5843	137.7014	193.5713
18	6 1 76	11	179.0000	35.5275	155.1338	202.8662
19	27 1 76	11	155.2727	28.4889	136.1348	174.4106
20	17 2 76	11	178.4545	29.1079	158.9008	198.0083
21	9 3 76	11	157.5455	60.3645	116.9946	198.0963
22	30 3 76	11	138.0000	45.9913	107.1045	168.8955
23	21 4 76	11	140.5455	35.3507	116.7980	164.2929
24	11 5 76	11	174.0909	45.7853	143.3339	204.8480
25	1 6 76	11	167.6364	36.3628	143.2090	192.0637
26	22 6 76	10	212.2000	92.2940	146.1815	278.2185
27	13 7 76	8	166.0000	45.9067	127.6149	204.3851
28	3 8 76	11	166.1818	72.6289	117.3921	214.9716
29	24 8 76	11	169.7273	48.4254	137.1967	202.2579
30	14 9 76	11	153.6364	58.1434	114.5775	192.6952
31	5 10 76	11	178.9091	68.2839	133.0382	224.7800
32	26 10 76	11	193.2727	41.6584	165.2880	221.2574
33	16 11 76	11	198.6364	76.8704	146.9974	250.2754
34	7 12 76	11	221.4545	74.8937	171.1434	271.7657
35	28 12 76	11	287.4545	93.8130	224.4341	350.4750
36	18 1 77	11	234.0000	65.8210	189.7836	278.2164
37	8 2 77	11	320.7273	209.8347	179.7672	461.6874
38	1 3 77	11	236.7273	126.2482	151.9178	321.5367
39	22 3 77	11	203.9091	125.3263	119.7190	288.0992
40	12 4 77	11	204.1818	119.5523	123.8705	284.4932
41	3 5 77	10	198.4000	148.0204	92.5199	304.2801
42	24 5 77	11	197.6364	117.1087	118.9666	276.3062
43	14 6 77	11	247.4545	125.9582	162.8399	332.0692
44	5 7 77	11	171.9091	61.0728	130.8824	212.9358
45	26 7 77	11	237.4545	112.4565	161.9099	312.9992
46	16 8 77	11	229.5455	115.7500	151.7884	307.3025
47	6 9 77	11	240.3636	107.2896	168.2900	312.4373
48	27 9 77	11	197.7273	113.8359	121.2560	274.1985
49	18 10 77	11	198.1818	85.2782	140.8947	255.4689
50	8 11 77	11	188.7273	81.9574	133.6710	243.7836

CONTINUATION

STATISTICAL ANALYSIS OF MEASURMENTS FROM 1 12 74 UNTIL 30 12 79
POLLUTING FACTOR - TDS MG/L

MEASUR MENTS NO.	DATE OF MEASURMENTS			NUMBER WELLS	MEAN	STANDARD DEVIATION	95 % CONFIDENCE INTERVAL FOR MEAN	
							LOWER LIMIT	UPPER LIMIT
51	6	12	77	11	178.1818	71.4728	130.1687	226.1949
52	20	12	77	11	201.8182	77.7558	149.5844	254.0520
53	10	1	78	11	186.7273	68.0957	140.9828	232.4717
54	1	2	78	11	201.4545	67.4394	156.1510	246.7581
55	22	2	78	11	178.7273	76.9897	127.0081	230.4465
56	15	3	78	11	222.3636	94.2287	159.0639	285.6634
57	4	4	78	11	215.0909	72.0187	166.7111	263.4707
58	26	4	78	11	219.8182	77.8740	167.5050	272.1314
59	17	5	78	11	254.5455	80.2700	200.6227	308.4682
60	7	6	78	11	250.7273	137.0322	158.6735	342.7810
61	28	6	78	11	235.4545	108.7422	162.4051	308.5040
62	19	7	78	10	295.4000	185.7550	162.5281	428.2719
63	9	8	78	10	261.8000	128.7010	169.7392	353.8608
64	30	8	78	10	245.8000	113.1624	164.8541	326.7459
65	20	9	78	11	314.7273	85.6284	257.2049	372.2496
66	11	10	78	10	265.2000	150.0317	157.8812	372.5188
67	3	11	78	11	277.4545	135.7972	186.2304	368.6786
68	22	11	78	11	292.3636	149.4679	191.9560	392.7713
69	13	12	78	10	300.0000	233.8280	132.7411	467.2589
70	21	1	79	11	395.8182	242.4697	232.9350	558.7014
71	6	2	79	11	255.8182	74.8837	205.5138	306.1226
72	2	3	79	11	388.7273	290.4345	193.6229	583.8317
73	21	3	79	11	384.0000	269.8844	202.7005	565.2995
74	12	4	79	11	280.5455	160.5044	172.7238	388.3671
75	3	5	79	11	266.5455	138.3679	173.5944	359.4965
76	22	5	79	11	328.9091	160.8959	220.8245	436.9937
77	13	6	79	10	354.2000	192.8372	216.2622	492.1378
78	3	7	79	11	279.0909	118.0792	199.7692	358.4126
79	25	7	79	10	340.6000	172.4260	217.2625	463.9375
80	21	8	79	11	292.3636	111.4767	217.4772	367.2500
81	7	9	79	11	307.2727	118.2447	227.8398	386.7057
82	29	9	79	11	197.2727	53.4211	161.3862	233.1593
83	17	10	79	10	203.6000	59.5151	161.0284	246.1716
84	7	11	79	11	251.6364	92.1556	189.7292	313.5435
85	28	11	79	10	238.8000	66.3606	191.3318	286.2682
86	20	12	79	11	215.8182	72.2299	167.2965	264.3399

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BOI-PWB
DATE  15/04/80


STATISTICAL  ANALYSIS  OF  MEASURMENTS  FROM    1  12  74  UNTIL    30  12  79
POLLUTING  FACTOR   -  CL-     MG/L

-------------------------------------------------------------------------------------------
WELLS  NUMB.         MEAN          STANDARD        CONFIDENCE       MINIMUM        MAXIMUM
       MEASUR                      DEVIATION      HALFINTERVAL       VALUE          VALUE
 NO.   MENTS                                        FOR MEAN
  I     N(I)         X(I)            S(I)             D(I)            XMIN           XMAX
-------------------------------------------------------------------------------------------
  1      78         30.7628         24.1303          5.4490          8.0000       111.0000
  2      84         32.8533         21.7171          4.7209         10.0000       104.0000
  3      86         28.6935         18.1735          3.9031         10.0000       111.0000
  5      86         20.0306         10.1722          2.1846          6.5000        49.0000
  6      86         37.6857         22.4001          4.8108         12.5000        96.0000
  7      85         19.0587          8.5195          1.8407          4.0000        48.0000
  8      86         14.3947          5.5656          1.1953          5.0000        34.0000
  9      86         23.1843          7.9893          1.7158         10.5000        57.0000
 10      86         21.5760          7.4767          1.6057          0.0000        55.0000
 13      82         21.5976         11.2849          2.4837          9.5000        62.0000
 14      86         26.4990         13.1122          2.8161          7.0000        91.0000
-------------------------------------------------------------------------------------------
SUM     931         25.0780         16.3083          1.0476
-------------------------------------------------------------------------------------------
MAXIMUM  AVERAGE  POLLUTION                 -     37.685698   WELLS    6
MINIMUM  AVERAGE  POLLUTION                 -     14.394651   WELLS    8
MAXIMUM  VALUE  OF  MEAN  DIFFERENCE        -     23.291047
MAXIMUM  VARIANCE                           -    582.270937   WELLS    1
MINIMUM  VARIANCE                           -     30.975402   WELLS    8
VALUE  OF  F-TEST                           -     18.797849
```

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BOI-FWB
DATE  15/04/80

STATISTICAL  ANALYSIS  OF  MEASURMENTS  FROM     1  12  74  UNTIL    30  12  79
POLLUTING  FACTOR   -  CL-      MG/L

EMPIRICAL  DISTRIBUTIONS
N(I) - NUMBER  OF  MEASURMENTS  IN  THE  I-TH  CLASS
F'(I)- FREQUENCY  IN  I-TH  CLASS
F(I) - CUMULATED  FREQUENCY  IN  I-TH  CLASS
----------------------------------------------------------------------------------------------------------------
WELLS
                             C L A S S     I N T E R V A L S
            ------------------------------------------------------------------------------------------------
 NO.           UNDER     FR   10.   FR   20.   FR   30.   FR   40.   FR   50.   FR   60.   FR   70.    OVER
                 10.     TO   20.   TO   30.   TO   40.   TO   50.   TO   60.   TO   70.   TO   80.     80.
----------------------------------------------------------------------------------------------------------------
   1   N(I)        2        38          9          8          8          4          3          1          5
       F'(I)  0.02564   0.48718    0.11538    0.10256    0.10256    0.05128    0.03846    0.01282    0.06410
       F(I)   0.02564   0.51282    0.62821    0.73077    0.83333    0.88462    0.92308    0.93590    1.00000
----------------------------------------------------------------------------------------------------------------
   2   N(I)        0        34          5         19         12          6          2          1          5
       F'(I)  0.00000   0.40476    0.05952    0.22619    0.14286    0.07143    0.02381    0.01190    0.05952
       F(I)   0.00000   0.40476    0.46429    0.69048    0.83333    0.90476    0.92857    0.94048    1.00000
----------------------------------------------------------------------------------------------------------------
   3   N(I)        0        30         23         19          5          4          3          0          2
       F'(I)  0.00000   0.34884    0.26744    0.22093    0.05814    0.04651    0.03488    0.00000    0.02326
       F(I)   0.00000   0.34884    0.61628    0.83721    0.89535    0.94186    0.97674    0.97674    1.00000
----------------------------------------------------------------------------------------------------------------
   5   N(I)        6        48         15         12          5          0          0          0          0
       F'(I)  0.06977   0.55814    0.17442    0.13953    0.05814    0.00000    0.00000    0.00000    0.00000
       F(I)   0.06977   0.62791    0.80233    0.94186    1.00000    1.00000    1.00000    1.00000    1.00000
----------------------------------------------------------------------------------------------------------------
   6   N(I)        0        26         12         13         12          6         10          2          5
       F'(I)  0.00000   0.30233    0.13953    0.15116    0.13953    0.06977    0.11628    0.02326    0.05814
       F(I)   0.00000   0.30233    0.44186    0.59302    0.73256    0.80233    0.91860    0.94186    1.00000
----------------------------------------------------------------------------------------------------------------
   7   N(I)        6        49         18          8          4          0          0          0          0
       F'(I)  0.07059   0.57647    0.21176    0.09412    0.04706    0.00000    0.00000    0.00000    0.00000
       F(I)   0.07059   0.64706    0.85882    0.95294    1.00000    1.00000    1.00000    1.00000    1.00000
----------------------------------------------------------------------------------------------------------------
   8   N(I)       11        65          7          3          0          0          0          0          0
       F'(I)  0.12791   0. 5581    0.08140    0.03488    0.00000    0.00000    0.00000    0.00000    0.00000
       F(I)   0.12791   0.88372    0.96512    1.00000    1.00000    1.00000    1.00000    1.00000    1.00000
----------------------------------------------------------------------------------------------------------------
   9   N(I)        0        30         44          8          2          2          0          0          0
       F'(I)  0.00000   0.34884    0.51163    0.09302    0.02326    0.02326    0.00000    0.00000    0.00000
       F(I)   0.00000   0.34884    0.86047    0.95349    0.97674    1.00000    1.00000    1.00000    1.00000
----------------------------------------------------------------------------------------------------------------
  10   N(I)        2        35         39          8          1          1          0          0          0
       F'(I)  0.02326   0.40698    0.45349    0.09302    0.01163    0.01163    0.00000    0.00000    0.00000
       F(I)   0.02326   0.43023    0.88372    0.97674    0.98837    1.00000    1.00000    1.00000    1.00000
----------------------------------------------------------------------------------------------------------------
  13   N(I)        1        50         15         10          1          4          1          0          0
       F'(I)  0.01220   0.60976    0.18293    0.12195    0.01220    0.04878    0.01220    0.00000    0.00000
       F(I)   0.01220   0.62195    0.80488    0.92683    0.93902    0.98780    1.00000    1.00000    1.00000
----------------------------------------------------------------------------------------------------------------
  14   N(I)        1        27         26         22          6          2          1          0          1
       F'(I)  0.01163   0.31395    0.30233    0.25581    0.06977    0.02326    0.01163    0.00000    0.01163
       F(I)   0.01163   0.32558    0.62791    0.88372    0.95349    0.97674    0.98837    0.98837    1.00000
----------------------------------------------------------------------------------------------------------------
SUM    N(I)       29       432        213        130         56         29         20          4         18
       F'(I)  0.03115   0.46402    0.22879    0.13963    0.06015    0.03115    0.02148    0.00430    0.01933
       F(I)   0.03115   0.49517    0.72395    0.86359    0.92374    0.95489    0.97637    0.98067    1.00000
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BOI-FWB
DATE  15/04/80

STATISTICAL  ANALYSIS  OF  MEASURMENTS  FROM     1  12  74  UNTIL    30  12  79
POLLUTING  FACTOR   -  CL-      MG/L

------------------------------------------------------------------------------------------------
MEASUR    DATE  OF     NUMBER        MEAN         STANDARD      95 %  CONFIDENCE INTERVAL
MENTS   MEASURMENTS    WELLS                      DEVIATION            FOR  MEAN
 NO.
-----------------------------------------------------------------------LOWER LIMIT   UPPER LIMIT---
   1     10  12  74        9        18.9056        10.1108        11.1337        26.6774
   2     14   1  75       10        16.0000         7.6413        10.5342        21.4658
   3      3   2  75       11        14.7727         5.0416        11.3859        18.1595
   4     18   3  75       11        16.1364         4.7386        12.9531        19.3196
   5      8   4  75       11        17.0455         6.4941        12.6830        21.4079
   6     29   4  75       11        17.5455         5.7639        13.6734        21.4175
   7     22   5  75       11        13.4091         3.2850        11.2024        15.6158
   8     12   6  75       11        14.4545         2.6311        12.6871        16.2220
   9      3   7  75       11        18.1364         5.9837        14.1167        22.1560
  10     23   7  75       11        16.9545         6.7692        12.4072        21.5019
  11     12   8  75       11        14.9091         2.4578        13.2580        16.5602
  12      1   9  75       11        14.3636         3.5291        11.9929        16.7344
  13     24   9  75       11        16.4091         4.0793        13.6687        19.1494
  14     14  10  75       11        14.4545         1.4570        13.4758        15.4333
  15      4  11  75       11        14.4091         3.3153        12.1820        16.6362
  16     25  11  75       11        14.8182         2.9772        12.8182        16.8182
  17     16  12  75       11        16.7273         2.3913        15.1209        18.3337
  18      6   1  76       11        19.0455        11.5552        11.2830        26.8079
  19     27   1  76       11        14.4091         3.5973        11.9925        16.8257
  20     17   2  76       11        15.2273         6.6609        10.7527        19.7019
  21      9   3  76       11        17.0909         6.4219        12.7769        21.4049
  22     30   3  76       11        17.7273        11.8751         9.7500        25.7046
  23     21   4  76       11        13.9091         1.8141        12.6904        15.1277
  24     11   5  76       11        13.5455         3.2974        11.3304        15.7605
  25      1   6  76       11        16.6364         3.5853        14.2279        19.0449
  26     22   6  76       10        13.7500         3.4661        11.2707        16.2293
  27     13   7  76       10        17.0500         5.5400        13.0872        21.0128
  28      3   8  76       11        14.5000         2.4900        12.8273        16.1727
  29     24   8  76       11        17.3636         2.2482        15.8533        18.8739
  30     14   9  76       11        17.0909         7.4223        12.1048        22.0770
  31      5  10  76       11        18.1818         4.8748        14.9071        21.4565
  32     26  10  76       11        18.1818         4.9964        14.8254        21.5382
  33     16  11  76       11        14.0000         2.8983        12.0530        15.9470
  34      7  12  76       11        22.5455        10.1031        15.7585        29.3324
  35     28  12  76       11        23.6364         8.6634        17.8166        29.4562
  36     18   1  77       11        24.0909         7.3818        19.1321        29.0498
  37      8   2  77       11        23.2727        11.2258        15.7316        30.8138
  38      1   3  77       11        23.0000        15.8619        12.3445        33.6555
  39     22   3  77       11        22.7273        15.2846        12.4596        32.9949
  40     12   4  77       11        24.8182        15.4714        14.4250        35.2113
  41      3   5  77       10        28.0000        21.5767        12.5660        43.4340
  42     24   5  77       11        25.6364        16.7348        14.3945        36.8783
  43     14   6  77       11        31.6364        10.3370        24.6923        38.5805
  44      5   7  77       11        28.4091        12.6941        19.8816        36.9366
  45     26   7  77       11        26.0909        12.1116        17.9547        34.2271
  46     16   8  77       11        29.4545        13.6775        20.2665        38.6426
  47      6   9  77       11        24.5455        12.2177        16.3380        32.7529
  48     27   9  77       11        23.4545        10.6898        16.2735        30.6356
  49     18  10  77       11        29.0909         9.1701        22.9307        35.2511
  50      8  11  77       11        20.6364        11.0478        13.2148        28.0579
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CONTINUATION

STATISTICAL ANALYSIS OF MEASURMENTS FROM 1 12 74 UNTIL 30 12 79
POLLUTING FACTOR - CL- MG/L

MEASUR MENTS NO.	DATE OF MEASURMENTS	NUMBER WELLS	MEAN	STANDARD DEVIATION	95 % CONFIDENCE INTERVAL FOR MEAN	
					LOWER LIMIT	UPPER LIMIT
51	6 12 77	11	21.0909	10.9586	13.7293	28.4525
52	20 12 77	11	25.6364	13.9948	16.2351	35.0376
53	10 1 78	11	29.7273	11.8667	21.7556	37.6989
54	1 2 78	11	21.6364	7.1172	16.8553	26.4175
55	22 2 78	11	25.4545	13.1253	16.6374	34.2717
56	15 3 78	11	31.3636	13.7933	22.0978	40.6295
57	4 4 78	11	31.8182	10.1668	24.9885	38.6479
58	26 4 78	11	29.1818	11.2501	21.6244	36.7392
59	17 5 78	11	31.8182	12.3921	23.4936	40.1428
60	7 6 78	11	32.4545	22.2817	17.4865	47.4226
61	28 6 78	11	29.5455	18.3976	17.1865	41.9044
62	19 7 78	10	35.7000	19.8441	21.5054	49.8946
63	9 8 78	10	30.5000	15.3786	19.4996	41.5004
64	30 8 78	10	37.1000	14.2240	26.9255	47.2745
65	20 9 78	11	35.6364	9.6672	29.1423	42.1305
66	11 10 78	10	41.4000	21.5468	25.9874	56.8126
67	3 11 78	11	36.8182	17.6001	24.9950	48.6414
68	22 11 78	11	43.3636	20.8484	29.3584	57.3689
69	13 12 78	10	44.6000	35.8986	18.9215	70.2785
70	21 1 79	11	50.0909	29.2693	30.4288	69.7531
71	6 2 79	11	38.0000	11.1086	30.5376	45.4624
72	2 3 79	11	50.9091	37.2302	25.8990	75.9191
73	21 3 79	11	55.3636	35.6743	31.3988	79.3285
74	12 4 79	11	38.1818	21.8395	23.5108	52.8529
75	3 5 79	11	32.9091	22.2237	17.9800	47.8382
76	22 5 79	11	43.1818	26.1336	25.6261	60.7375
77	13 6 79	10	45.1000	23.6711	28.1679	62.0321
78	3 7 79	11	27.3636	15.7370	16.7920	37.9353
79	25 7 79	10	24.5000	14.5621	14.0836	34.9164
80	21 8 79	11	18.3636	7.2010	13.5262	23.2010
81	7 9 79	11	20.9091	8.1050	15.4644	26.3538
82	29 9 79	11	27.1818	8.4949	21.4752	32.8884
83	17 10 79	10	26.8000	7.7143	21.2819	32.3181
84	7 11 79	11	28.4545	8.8359	22.5189	34.3902
85	28 11 79	10	30.5000	9.7439	23.5301	37.4699
86	20 12 79	11	30.6364	10.3370	23.6923	37.5805

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BOI-PWB
DATE  15/04/80

STATISTICAL  ANALYSIS  OF  MEASURMENTS  FROM     1  12  74  UNTIL    30  12  79
POLLUTING  FACTOR    -  SO4=     MG/L

------------------------------------------------------------------------------------------
WELLS   NUMB.       MEAN         STANDARD       CONFIDENCE       MINIMUM       MAXIMUM
        MEASUR                   DEVIATION     HALFINTERVAL      VALUE         VALUE
 NO.    MENTS                                    FOR MEAN
  I      N(I)       X(I)          S(I)            D(I)           XMIN          XMAX
------------------------------------------------------------------------------------------
  1      78       116.5769       81.8588         18.4849        34.0000       404.0000
  2      84       116.3048       72.1551         15.6852        39.0000       354.0000
  3      86        89.8209       67.8593         14.5739        13.0000       374.0000
  5      86        62.8616       28.5103          6.1231        11.6000       153.0000
  6      86        78.1337       46.7273         10.0355         5.5000       240.0000
  7      85        22.4424       26.6237          5.7524         4.0000       184.0000
  8      86        28.3721       17.2501          3.7048         8.0000       101.0000
  9      86        62.5733       35.4937          7.6229        19.4000       235.0000
 10      86        48.2791       25.3662          5.4478        11.0000       201.0000
 13      82        69.2146       34.1858          7.5240        11.0000       190.0000
 14      86        72.9360       44.3728          9.5298        11.0000       365.0000
------------------------------------------------------------------------------------------
SUM     931        69.3252       55.6773          3.5765
------------------------------------------------------------------------------------------
MAXIMUM  AVERAGE  POLLUTION                -     116.576923    WELLS     1
MINIMUM  AVERAGE  POLLUTION                -      22.442353    WELLS     7
MAXIMUM  VALUE  OF  MEAN  DIFFERENCE       -      94.134570
MAXIMUM  VARIANCE                          -    6700.870889    WELLS     1
MINIMUM  VARIANCE                          -     297.567447    WELLS     8
VALUE  OF  F-TEST                          -      22.518830
```

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BOI-PWB
DATE  15/04/80

STATISTICAL  ANALYSIS  OF  MEASURMENTS  FROM    1  12  74  UNTIL   30  12  79
POLLUTING  FACTOR   -   SO4=    MG/L

EMPIRICAL  DISTRIBUTIONS
N(I) - NUMBER  OF  MEASURMENTS  IN  THE  I-TH  CLASS
F'(I)- FREQUENCY  IN  I-TH  CLASS
F(I) - CUMULATED  FREQUENCY  IN  I-TH  CLASS
--------------------------------------------------------------------------------------------------------------
WELLS
                              C L A S S     I N T E R V A L S
             ---------------------------------------------------------------------------------------------
 NO.           UNDER    FR   40.  FR   70.  FR  100.  FR  130.  FR  160.  FR  190.  FR  220.     OVER
                 40.    TO   70.  TO  100.  TO  130.  TO  160.  TO  190.  TO  220.  TO  250.     250.
--------------------------------------------------------------------------------------------------------------
  1   N(I)         1        21        27        12         3         2         3         2         7
      F'(I)  0.01282   0.26923   0.34615   0.15385   0.03846   0.02564   0.03846   0.02564   0.08974
      F(I)   0.01282   0.28205   0.62821   0.78205   0.82051   0.84615   0.88462   0.91026   1.00000
--------------------------------------------------------------------------------------------------------------
  2   N(I)         1        20        32        10         3         4         3         4         7
      F'(I)  0.01190   0.23810   0.38095   0.11905   0.03571   0.04762   0.03571   0.04762   0.08333
      F(I)   0.01190   0.25000   0.63095   0.75000   0.78571   0.83333   0.86905   0.91667   1.00000
--------------------------------------------------------------------------------------------------------------
  3   N(I)        12        31        22         8         2         3         2         2         4
      F'(I)  0.13953   0.36047   0.25581   0.09302   0.02326   0.03488   0.02326   0.02326   0.04651
      F(I)   0.13953   0.50000   0.75581   0.84884   0.87209   0.90698   0.93023   0.95349   1.00000
--------------------------------------------------------------------------------------------------------------
  5   N(I)        12        46        16        11         1         0         0         0         0
      F'(I)  0.13953   0.53488   0.18605   0.12791   0.01163   0.00000   0.00000   0.00000   0.00000
      F(I)   0.13953   0.67442   0.86047   0.98837   1.00000   1.00000   1.00000   1.00000   1.00000
--------------------------------------------------------------------------------------------------------------
  6   N(I)        22        12        26        17         6         1         1         1         0
      F'(I)  0.25581   0.13953   0.30233   0.19767   0.06977   0.01163   0.01163   0.01163   0.00000
      F(I)   0.25581   0.39535   0.69767   0.89535   0.96512   0.97674   0.98837   1.00000   1.00000
--------------------------------------------------------------------------------------------------------------
  7   N(I)        74         6         3         1         0         1         0         0         0
      F'(I)  0.87059   0.07059   0.03529   0.01176   0.00000   0.01176   0.00000   0.00000   0.00000
      F(I)   0.87059   0.94118   0.97647   0.98824   0.98824   1.00000   1.00000   1.00000   1.00000
--------------------------------------------------------------------------------------------------------------
  8   N(I)        64        20         1         1         0         0         0         0         0
      F'(I)  0.74419   0.23256   0.01163   0.01163   0.00000   0.00000   0.00000   0.00000   0.00000
      F(I)   0.74419   0.97674   0.98837   1.00000   1.00000   1.00000   1.00000   1.00000   1.00000
--------------------------------------------------------------------------------------------------------------
  9   N(I)        22        36        19         6         1         0         1         1         0
      F'(I)  0.25581   0.41860   0.22093   0.06977   0.01163   0.00000   0.01163   0.01163   0.00000
      F(I)   0.25581   0.67442   0.89535   0.96512   0.97674   0.97674   0.98837   1.00000   1.00000
--------------------------------------------------------------------------------------------------------------
 10   N(I)        40        34         9         2         0         0         1         0         0
      F'(I)  0.46512   0.39535   0.10465   0.02326   0.00000   0.00000   0.01163   0.00000   0.00000
      F(I)   0.46512   0.86047   0.96512   0.98837   0.98837   0.98837   1.00000   1.00000   1.00000
--------------------------------------------------------------------------------------------------------------
 13   N(I)        11        36        24         5         4         1         1         0         0
      F'(I)  0.13415   0.43902   0.29268   0.06098   0.04878   0.01220   0.01220   0.00000   0.00000
      F(I)   0.13415   0.57317   0.86585   0.92683   0.97561   0.98780   1.00000   1.00000   1.00000
--------------------------------------------------------------------------------------------------------------
 14   N(I)        12        37        26         4         5         1         0         0         1
      F'(I)  0.13953   0.43023   0.30233   0.04651   0.05814   0.01163   0.00000   0.00000   0.01163
      F(I)   0.13953   0.56977   0.87209   0.91860   0.97674   0.98837   0.98837   0.98837   1.00000
--------------------------------------------------------------------------------------------------------------
SUM   N(I)       271       299       205        77        25        13        12        10        19
      F'(I)  0.29108   0.32116   0.22019   0.08271   0.02685   0.01396   0.01289   0.01074   0.02041
      F(I)   0.29108   0.61224   0.83244   0.91515   0.94200   0.95596   0.96885   0.97959   1.00000
--------------------------------------------------------------------------------------------------------------
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BOI-PWB
DATE  15/04/80

STATISTICAL  ANALYSIS  OF  MEASURMENTS  FROM     1  12  74  UNTIL    30  12  79
POLLUTING  FACTOR    -  SO4=     MG/L

-------------------------------------------------------------------------------------------------
MEASUR    DATE  OF      NUMBER       MEAN         STANDARD      95 %  CONFIDENCE INTERVAL
MENTS   MEASURMENTS     WELLS                     DEVIATION             FOR  MEAN
 NO.                                                           LOWER LIMIT      UPPER LIMIT
-------------------------------------------------------------------------------------------------
   1     10  12  74        9        51.5556        7.9075        45.4774          57.6337
   2     14   1  75       10        49.7100       22.0594        33.9307          65.4893
   3      3   2  75       11        55.5727       24.6521        39.0122          72.1332
   4     18   3  75       11        45.2182       20.1370        31.6908          58.7456
   5      8   4  75       11        46.4455       21.4182        32.0574          60.8335
   6     29   4  75       11        46.5273       22.8750        31.1606          61.8940
   7     22   5  75       11        50.3545       26.2615        32.7129          67.9962
   8     12   6  75       11        33.3636       16.8717        22.0298          44.6975
   9      3   7  75       11        55.8909       17.0515        44.4362          67.3456
  10     23   7  75       11        46.2545       25.6454        29.0268          63.4823
  11     12   8  75       11        41.3818       29.8144        21.3535          61.4102
  12      1   9  75       11        44.8727       23.6639        28.9761          60.7693
  13     24   9  75       11        67.1273       18.7346        54.5420          79.7126
  14     14  10  75       11        34.4182       31.4908        13.2637          55.5727
  15      4  11  75       11        45.3636       25.5607        28.1928          62.5345
  16     25  11  75       11        54.4545       17.5634        42.6560          66.2531
  17     16  12  75       11        64.0182       30.3101        43.6569          84.3795
  18      6   1  76       11        40.4273       14.0752        30.9720          49.8826
  19     27   1  76       11        53.7636       32.1534        32.1641          75.3632
  20     17   2  76       11        56.9273       27.5112        38.4461          75.4084
  21      9   3  76       11        37.6364       21.8599        22.9516          52.3211
  22     30   3  76       11        43.7273       31.8845        22.3083          65.1462
  23     21   4  76       11        44.2727       22.4503        29.1913          59.3541
  24     11   5  76       11        47.1273       23.5819        31.2857          62.9689
  25      1   6  76       11        43.5636       18.6946        31.0052          56.1220
  26     22   6  76       10        43.5800       25.7289        25.1759          61.9841
  27     13   7  76       10        43.6000       23.0492        27.1127          60.0873
  28      3   8  76       11        83.8182       61.0644        42.7971         124.8393
  29     24   8  76       11        34.5909       19.7076        21.3520          47.8299
  30     14   9  76       11        45.4364       26.1705        27.8559          63.0168
  31      5  10  76       11        43.8909       27.3350        25.5281          62.2537
  32     26  10  76       11        51.8000       24.9663        35.0284          68.5716
  33     16  11  76       11        66.5545       28.1670        47.6329          85.4762
  34      7  12  76       11        52.3091       18.7303        39.7267          64.8915
  35     28  12  76       11        67.3273       29.0148        47.8361          86.8185
  36     18   1  77       11        62.0455       21.0838        47.8821          76.2088
  37      8   2  77       11        53.9545       24.6485        37.3965          70.5126
  38      1   3  77       11        62.4000       27.5897        43.8662          80.9338
  39     22   3  77       11        65.5909       40.2642        38.5428          92.6391
  40     12   4  77       11        67.7273       30.5879        47.1793          88.2752
  41      3   5  77       10        56.3000       35.5248        30.8889          81.7111
  42     24   5  77       11        57.7273       30.4075        37.3005          78.1541
  43     14   6  77       11        71.2727       40.6598        43.9588          98.5866
  44      5   7  77       11        49.0909       21.6041        34.5780          63.6039
  45     26   7  77       11        49.0364       26.0412        31.5427          66.5300
  46     16   8  77       11        57.8727       30.9957        37.0508          78.6946
  47      6   9  77       11        53.6000       29.2184        33.9720          73.2280
  48     27   9  77       11        56.5091       30.9019        35.7502          77.2679
  49     18  10  77       11        58.6364       30.5525        38.1122          79.1605
  50      8  11  77       11        49.5455       28.3809        30.4801          68.6108
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CONTINUATION

STATISTICAL ANALYSIS OF MEASURMENTS FROM 1 12 74 UNTIL 30 12 79
POLLUTING FACTOR - SO4= MG/L

MEASUR MENTS NO.	DATE OF MEASURMENTS	NUMBER WELLS	MEAN	STANDARD DEVIATION	95 % CONFIDENCE INTERVAL FOR MEAN	
					LOWER LIMIT	UPPER LIMIT
51	6 12 77	11	55.3636	38.7589	29.3267	81.4006
52	20 12 77	11	58.3636	33.9125	35.5824	81.1449
53	10 1 78	11	72.3636	24.8406	55.67[illegible]5	89.0507
54	1 2 78	11	52.9091	36.5444	28.3598	77.4584
55	22 2 78	11	49.1818	26.9177	31.0994	67.2643
56	15 3 78	11	70.0909	42.0249	41.8600	98.3219
57	4 4 78	11	66.6364	35.7667	42.6095	90.6632
58	26 4 78	11	68.5455	50.2481	34.7904	102.3005
59	17 5 78	11	81.2727	35.5727	57.3761	105.1693
60	7 6 78	11	90.5455	58.3890	51.3217	129.7693
61	28 6 78	11	67.2727	51.0570	32.9743	101.5712
62	19 7 78	10	72.9000	57.1090	32.0495	113.7505
63	9 8 78	10	74.2000	56.3438	33.8969	114.5031
64	30 8 78	10	74.5000	52.1371	37.2060	111.7940
65	20 9 78	11	115.6364	58.8664	76.0918	155.1809
66	11 10 78	10	97.3000	80.3341	39.8364	154.7636
67	3 11 78	11	83.3636	53.0439	47.7305	118.9968
68	22 11 78	11	127.6364	90.9222	66.5578	188.7150
69	13 12 78	10	122.0000	116.6371	38.5686	205.4314
70	21 1 79	11	159.0909	123.4613	76.1537	242.0282
71	6 2 79	11	85.6364	38.0796	60.0557	111.2170
72	2 3 79	11	149.3636	145.5777	51.5693	247.1579
73	21 3 79	11	153.4545	148.8915	53.4341	253.4750
74	12 4 79	11	118.0000	73.2639	68.7837	167.2163
75	3 5 79	11	119.3636	78.6553	66.5256	172.2017
76	22 5 79	11	136.2727	70.9705	88.5970	183.9484
77	13 6 79	10	148.9000	74.4333	95.6573	202.1427
78	3 7 79	11	113.9091	66.8767	68.9835	158.8347
79	25 7 79	10	137.1000	96.0190	68.4169	205.7831
80	21 8 79	11	112.6364	65.4695	68.6561	156.6166
81	7 9 79	11	120.6364	63.7813	77.7902	163.4826
82	29 9 79	11	62.5455	24.7684	45.9069	79.1840
83	17 10 79	10	56.0000	24.5447	38.4430	73.5570
84	7 11 79	11	65.0909	27.9766	46.2971	83.8847
85	28 11 79	10	64.9000	26.4300	45.9944	83.8056
86	20 12 79	11	64.2727	28.8413	44.8981	83.6473